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Upper Columbia River Steelhead and Spring Chinook Salmon Quantitative Analysis Report

Run Reconstructions and Preliminary Assessment of Extinction Risks

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Upper Columbia Quantitative Assessment Report
Analytical Requirements Committee

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Executive Summary

The Upper Columbia Quantitative Analysis Report (QAR) process was established to provide decision makers with current assessments of the status of spring chinook and steelhead runs returning to the Wenatchee, Entiat and Methow river systems. Production of spring chinook and steelhead from these three tributaries along with the Okanogan River constitutes the Upper Columbia spring chinook and the Upper Columbia steelhead Evolutionarily Significant Units (ESUs), respectively[1]. The two Upper Columbia ESUs were listed as 'threatened' under the Endangered Species Act in 1998. The purpose of this report is to provide hypothetical estimates of the relative risks of extinction under a range of alternative management and climatic/environmental scenarios and to estimate the survival gains necessary to meet interim recovery levels.

Simple population dynamics models were developed for upper Columbia Spring Chinook (Wenatchee, Entiat and Methow populations) and summer steelhead (Wenatchee/Entiat, Methow populations). Reconstructed spawner to spawner return ratios for historical years, estimated age at return data and estimates of recent spawning escapements were used as input into a stochastic cohort run reconstruction (CRR) statistical model. The model was designed to generate hypothetical time trends in return levels and the effect of survival changes on those trends. Alternative assumptions regarding the effectiveness of hatchery origin spawners are considered in the analysis. Model development, assumptions, and simulations were reviewed by an analytical team consisting of representatives from Chelan, Douglas, and Grant PUDs, BPA, WDFW, CRITFC, and CBFWA.

The proposed Mid-Columbia HCP incorporated a framework designed to address project impacts on migrating salmon and steelhead through a combination of survival improvements at the projects, off-site habitat mitigation and hatchery programs. The focus of the analyses described in this report is on identifying levels of life cycle survival improvements necessary for the listed stocks to be self-sustaining. The report includes specific assessments of the potential benefits of meeting of the passage survival and habitat objectives of the draft HCP for each of the five Mid-Columbia projects. In the longer term, achieving conditions that result in survival levels high enough to support self-sustaining natural production is an important objective under the ESA. The hatchery mitigation component of the HCP is essential for achieving the mitigation objective of no net impact as a result of the mid-Columbia hydropower projects.

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[1]The QAR Biological Requirements Workgroup identified three independent, viable populations of spring chinook and steelhead in the upper Columbia Basin (Wenatchee, Entiat, and Methow populations). Because of data limitations, Entiat and Wenatchee steelhead were modeled as a single group. Recovery goals for steelhead in the Okanogan system are deferred to the Upper Columbia Recovery Team.

Under NMFS guidelines, hatchery production is explicitly not included in the assessment of long term sustainability of a stock. However, hatchery supplementation can play a separate and important role in the overall approach to addressing particular ESA listed stock problems . In the short term, hatchery supplementation can play a major role in preserving opportunities for survival improvements to be implemented and for speeding up the rebuilding process.

The population models of upper Columbia spring chinook and steelhead were used to explore four basic questions. First, what are the relative risks of extinction under alternative assumptions about future environmental conditions? Second, how much improvement in survival across the life history of a particular run is necessary to meet extinction risk and rebuilding criteria under alternative assumptions regarding future environmental conditions? Third, what benefits in terms of life cycle survival would be gained by meeting the specific survival improvement goals in the Mid-Columbia HCP?. Fourth, assuming that the survival objectives set forth in the draft Mid-Columbia HCP and the Federal Columbia River Power System (FCRPS) Biological Opinion are met, would the cumulative improvement in survival meet or exceed population specific survival improvement goals?

It is important to note that although the proposed Mid-Columbia HCP is intended to improve the survival of upper Columbia River chinook and steelhead, it is not intended, by itself, to be the only action responsible for meeting ESU survival and recovery objectives. In determining whether or not a particular action jeopardizes the continued existence of a listed ESU, NMFS determines "..whether the species can be expected to survive with an adequate potential for recovery under the effects of the proposed or continuing action, the effects of the environmental baseline, and any cumulative effects, and considering measures for survival and recovery specific to other life stages."[2]

Because we cannot accurately predict future environmental/climatic conditions, we used information from three different sets of years within the chinook data series to capture a possible range of future conditions. Spawner-return data for the Upper Columbia spring chinook runs dates back to 1960. Annual spawner return rates were generally higher for broods originating in the 1960's than in later years. Return levels for broods originating in the early 1990's included several of the lowest rates in the historical time series. Model runs using three different sets of spawner return data from the historical series were used to characterize the relative extinction risks and survival needs under alternative environmental conditions.

Model runs incorporating the average and variance in spawner return rates across the entire historical series (1960 - 94 brood years) represent an assumption that future conditions are best represented by the longest historical series that can be generated. This scenario would

[2] 2001 FCRPS Biological Opinion. Section 1.3

encompass assumptions that salmon survivals are strongly influenced by long-term (30-50 year) cycling in ocean/climatic conditions. The period 1980-1994 captures a time of relatively poor environmental/climatic conditions. If one assumes that poor environmental/climatic conditions will continue into the future (e.g., because of global warming), then results based on the time series 1980-1994 may be most useful. The period 1970-1994 may reflect an average condition that falls between the poor conditions represented by the 1980-1994 data series and the better conditions of the 1960-1994 series. Adding preliminary estimates of the 2000 and 2001 returns to extend the 1980-94 data series resulted in mean spawner/return rates similar to the 1970-94 data series. The spawner-return data series for Upper Columbia River steelhead is relatively short (1976-1994), therefore we did not attempt to generate alternative future survival and extinction risks for steelhead as we did for spring chinook.

The results from these simulations should not be viewed as specific predictions of future conditions or stock status. Rather, these models are tools intended to illustrate the potential response of the population to a range of future scenarios given a set of assumptions regarding population dynamics. While those assumptions are based on the best available information, there is considerable uncertainty associated with many of the estimates. This report includes sensitivity analyses designed to illustrate the influence of uncertainty in selected key assumptions on model results.

Current Extinction Risks

The CRR model estimated the relative risk of extinction of spring chinook populations at 24, 48, and 100 years and for steelhead at 25, 50, 75, and 100 years.[3] The majority of the extinction risk assessments described in this report are expressed in terms of absolute extinction - defined as the probability that chinook or steelhead populations fall to one or fewer spawners in five or more consecutive years. Given the uncertainty associated with productivity at extremely low levels of escapement, an quasi-extinction risk assessments were also applied to chinook model populations. Quasi-extinction risk was estimated as the probability that chinook runs would fall to 50 or fewer spawners in the Methow and Wenatchee basins and 30 or fewer in the Entiat Basin for five or more consecutive years.[4] For each scenario analyzed, the model was run for 1,000 iterations. Relative extinction risk at each of the selected time intervals was expressed as the percentage of 1,000 runs projected to be at or below the selected extinction level.

Extinction risk assessments based on simple population models are sensitive to assumptions regarding the average and distribution of spawner return rates and to the starting population size. Spawner return rates (geometric mean and variances) were calculated for the alternative time series described above. Two alternative estimates of starting population size were used. Under

[3]Estimated returns of chinook to the upper Columbia tributaries were based on annual redd counts dating back to the late 1950's and early 1960's. Estimated returns of steelhead were based on dam counts.

[4]The risk criteria are described in the QAR Biological Requirements Report (Ford ,1999)

the first approach, recent (1995-99) average spawning escapement estimates were used as the basis for starting population size. Projections of the trend in spawning escapements from the initial level were generated by the simple population model using the spawner return rate estimates as a basis for generating production from each spawning year. A second starting point was used to simulate extinction risks given initial achievement of recovery abundance levels as a result of supplementation, but without long-term improvement in mean spawner to spawner return levels. Under this set of scenarios, the starting point for the analyses were initial spawning escapements at the Interim Recovery Levels recommended for each of the upper Columbia populations.[5]

Spring Chinook Extinction Risks
Extinction risks varied among the three upper Columbia spring chinook population areas. In general, the modeling analysis indicated that the Wenatchee River population has the highest current risk of extinction the three runs. Extinction risk levels were sensitive to the time period used to derive survival/production characteristics.

Annual return rates since 1980 have been highly variable and have included the lowest estimated return per spawner rates in the record. Assuming that conditions into the future will continue at levels associated with the 1980-94 brood year data series results in high probabilities of extinction in 50 to 100 years for all upper Columbia steelhead stocks.

Assuming that future conditions are best represented by the historical series extending back to brood year 1970 generally reduces extinction risks in the Wenatchee and Entiat analyses. For the Methow analysis, extending the series back to 1970 did not change the projected extinction risk substantially. Dam counts of adult and jack spring chinook in 2000 indicate relatively high return rates for the 1995 and 1996 brood years. Incorporating projections for these brood years into the extinction analysis results in projections similar to the 1970 to the present data set.

Assuming future conditions would include survivals like we have seen since the early 1960's results in a large decrease in extinction risks relative to the assumption that survivals will remain at the lower levels seen since the 1980. However, improvements in average population growth rate would still be necessary to lower extinction risks to below levels being considered as criteria.

The extinction risk projections described above were generated assuming that the geometric mean return per spawner and the observed level of year to year variation about that mean for each historical series would continue to apply into the future. There is uncertainty associated with the estimates of trend. A simple modeling analysis using the Wenatchee spring chinook data series was conducted to assess the effect of uncertainty in the trend estimate on the projected extinction

[5]Interim Recovery Levels are described in the QAR Biological Requirements Report (Ford, 2001)

risk. (section 4.1.2.5). Assuming that the estimated geometric mean trend continues, the point estimate of extinction risk using the 1980 Wenatchee data series was 98% at 100 years. Incorporating uncertainty in the historical trend estimate generated a range about that point estimate but a high proportion of the results projected relatively high risks of extinction. For example, 90% of the runs based on the 1980-94 data set incorporating uncertainty projected 100 year extinction probabilities of 31% or higher. Using the 1970-94 data set, approximately 75% of the runs projected 100 year extinction rates of 31% or higher.

Steelhead Extinction Risks
As described above, more limited trend data are available for upper Columbia steelhead. The parameters for the steelhead extinction risk model were derived from the 1986-92 brood year data sets for the Wenatchee/Entiat and the Methow steelhead runs. A significant proportion of returns to these areas are of hatchery origin. The relative effectiveness of hatchery origin spawners is a key unknown. Extinction risk estimates were generated for a range of possible relative effectiveness values for naturally spawning fish of direct hatchery origin. As was the case with spring chinook, the extinction risk assessments for steelhead were designed to evaluate the potential for runs to sustain production if hatchery supplemenation were to be discontinued. Given these assumptions, the projected 50, 75 and 100 year extinction risks for both of the upper Columbia production groupings were extremely high. The level of risk was influenced by assumptions regarding the historical effectiveness of hatchery contributions relative to spawners of natural origin. Extinction risk projections were estimated to be approximately 28-35% under the assumption of low (25%) relative effectiveness of spawners. Under the assumption that the effectiveness is .75 or less relative to wild fish, the projected extinction risks for both groups are on the order of 95-100%

Supplementation Scenarios
Simplified supplementation scenarios were evaluated with the CRR model. Supplementation has the potential to accelerate the return of spawning numbers to Interim Recovery levels. Under the assumption that the ESU's should be capable of sustaining themselves without supplementation, model runs were made under the assumption that run sizes were boosted to the Interim Recovery Level and extinction risks were calculated as described above. Under the assumption that 1980-present population survival rates continues, longer term (e.g., 100 yr) risks were nearly as high as for the runs starting from recent averages.

Survival Changes Needed to Meet Alternative Risk and Recovery Criteria

The CRR model was also used to generate estimates of the average change in survival over the life cycle[6] needed to meet specific extinction risk criteria - e.g., less than a 5% risk of extinction as a result of year to year environmental variability and meeting Interim Recovery Level escapement objectives. Meeting the recommended Interim Recovery level escapement criteria requires a larger increase in survival than meeting the direct extinction risk criteria for all of the populations. The objective of maintaining average escapements at IRL or above is to provide protection against demographic, environmental and genetic factors.

Spring Chinook

Assuming background survival at were to continue at the relatively poor 1980-94 levels, the modeled Wenatchee spring chinook population would need a survival improvement of170% to meet the recovery escapement criteria (IRL) at 48 years. Meeting the IRL criteria at 100 years would require a survival increase of 155% under the 1980-94 assumptions.

If long-term background survivals are similar to the 1970-94 series, the requirements would drop to 92% and 110% to meet IRL criteria at 48 and 100 years, respectively. Assuming that the distribution of future survivals is represented by the longest time series, the range observed since 1960, results in required survival improvement increments of 40% and 15% for the 48 year and 100 year time periods.

Model runs based on the Methow spring chinook data set indicated similar levels of improvement would be required. Assuming that the long term series of spawner/return estimates (1960-94 brood years) represents future conditions, a 19% increase in life cycle survival would be required to reduce the projected extinction risk at 100 years to below 5%. A 48% increase in survival would be needed to meet and maintain IRL criteria within 100 years, a 52% increase to meet those criteria within 48 years.

Assuming that the relatively poor survival conditions indicated by the 1980-94 data series are representative of the future, meeting the 100 year direct extinction risk criteria would require a 32% increase in life cycle survival and meeting the IRL levels would require an increases of 95% (100 years) or 105% (48 years). Results for the Methow using the intermediate 1970-1994 time series were similar to the 1980-94 results.

Projections based on the Entiat spring chinook data set followed similar patterns. Under the assumption that the longer term data set - 1960-94 is representative of future conditions a relatively small increase of 2% in survival is required to reduce the projected extinction risk to 5%. IRL levels would be achieved with increases of 22% (48 year target) or 17% (100 year

[6]Changes necessary to meet particular risk criteria are expressed in terms of survival in this paper. These increments can be translated into changes in population growth rate, λ, using an estimate of average generation time for the particular population of interest.

target). Assuming that 1980-94 conditions are representative of the future results in projected survival improvement of 57% to reduce the 100 year extinction risk to 5%. Survival improvements of 95% or 105% would be required to meet IRL objectives at 100 years or 48 years, respectively. Using the 1970-94 data set to represent the future background conditions results in a projected survival improvement requirement of 18% to meet direct extinction criteria. Meeting IRL levels under this scenario requires life cycle survival improvements of 52% (100 year) or 62% (48 year time frame).

The improvement levels necessary to meet short term risks to extinction due to the compound effects of year to year environmental variation are less then the levels required to meet IRL for each model population. In general, the survival improvements to meet 48 year and 100 year extinction risk criteria are approximately one-third to one-half of the improvement levels required to meet IRL criteria.

Steelhead
The CRR model was used to estimate the improvement in life cycle survival needed to meet the basic extinction risk criteria described above. The results were substantially influenced by assumptions regarding the effectiveness of hatchery spawners in contributing to natural production. Model runs incorporating the Methow steelhead data series required the highest levels of improvement in life cycle survival to meet the criteria.

The Methow model runs indicated that an increase of 152% (1.52X) in survival over the life cycle would be required to meet the 100 year extinction risk criteria. Achieving the IRL level would require an improvement of 265% [7] under the assumption that hatchery steelhead spawners have been contributing equally with natural returns to production. Assuming that hatchery spawners were .25 as effective as returning adults of natural parentage, the survival change needed to meet the 100 year direct extinction risk criteria was 15%, and the change needed to meet IRL objectives was 55%. The survival changes needed to meet the 100 year risk criteria under the .50 and .75 effectiveness assumptions were 70% and 115%. Meeting the IRL targets under the .50 and .75 effectiveness assumptions required improvements of 135% and 200%, respectively.

Projected survival improvements for the Wenatchee/Entiat grouping were lower, but were still substantial. Meeting the direct extinction risk criteria of 5% risk or less by 100 years required 87% improvement in life cycle survival under the assumption that hatchery fish were equally

[7] For the steelhead model runs, recent average escapement levels (including hatchery fish) have been relatively high. There was little difference in the projected survival increases to meet IRL levels at 48 years vs 100 years.

effective. Meeting the IRL targets under the 1.0 hatchery effectiveness assumption required a 160% improvement in survival.

Under the assumption of equal hatchery spawner effectiveness, the survival improvements to meet the 100 year risk criteria and the IRL level were 12% and 50%, respectively. Assuming intermediate hatchery effectiveness assumptions of .50 and .75 resulted in projected survival increases of 45% and 67% to meet the 100 year risk criteria. Increases of 95% and 120% were projected to meet the IRL targets under the .50 and .75 effectiveness assumptions.

Upper Columbia steelhead returns have been predominately of hatchery origin since at least the late 1970's. The relative reproductive effectiveness of hatchery spawners vs returning adults from naturally spawning parents is unknown for the upper Columbia. Results of the modeling exercise support the contention that effectiveness is a key uncertainty relative to the level of survival improvements necessary to meet extinction risk and recovery criteria.

Sensitivity Analyses

The spring chinook version of the CRR model was used in a series of analyses to probe the sensitivity of results (extinction risks and the level of survival improvement necessary to meet criteria) to key assumptions.

Incorporating Preliminary Estimates of 1999-2001 Returns

Preliminary estimates of 1999-2001 returns were used to expand the 1980-94 brood year data series to include brood years 95 and 96 for the Wenatchee and Methow spring chinook data sets. Returns from these two brood years were significantly higher than for the recent series. The expanded data sets were analyzed with the CRR model. Extinction risks and the incremental improvements in survival necessary to meet survival and IRL criteria were reduced to approximately the same levels as were indicated by analyses of the 1970-94 data sets.

Carrying Capacity

The estimated increase in survival is sensitive to assumptions regarding carrying capacity of the systems. If carrying capacity is substantially higher that the IRL level, the survival improvement required to rebuild from recent average escapements to IRL is lower. For example, the requirement to meet the IRL escapement criteria for the Wenatchee (assuming future survivals are represented by the 1980-94 data series) is 170% assuming that maximum smolt production is reached at an escapement of 4,000 (approximately equal to the IRL level). The requirement drops below 100% improvement if the ceiling is roughly double the IRL level (7500). If the ceiling (spawning level producing maximum smolt output) is very high relative to the IRL, the required survival improvement is reduced to approximately 75%.

Stock-Recruit Model

The population modeling described in this paper was based largely on a simple 'broken stick' model relating productivity to spawning population size. Under this approach, production per spawner is constant up to a carrying capacity threshold. At escapements above that threshold, average production is constant. An alternative population function, the Ricker spawner/recruit function, has been fit to historical data from the upper Columbia stocks (Schaller et al., 2000). The CRR model was modified to implement the Ricker function derived from the 1970-94 brood year spawner/return series. Using the Ricker function resulted in lower projected extinction risks relative to the broken stick model assuming the 1970-94 average survivals would continue. Reducing survivals to the equivalent of 1980-94 levels resulted in high extinction risk probabilities, similar to the broken stick model. Achieving the IRL levels took higher increments of survival improvements than were required using the broken stick model.

Survival Changes at Different Life History Phases

The sensitivity of average annual population growth rate to changes in mortality at specific phases in the life cycle showed a similar pattern to Snake River analyses, with a couple of exceptions. The Snake River populations and the upper Columbia populations exhibit high mortality rates in the egg to smolt and the estuary to ocean adult phases. Shift of 10% mortality to survival could, theoretically, increase survival rates of 2-3 times. However, the resulting survivals would be higher than smolt production rates that are associated with relatively healthy stocks. The feasibility of particular actions to achieve survival increases that are mathematically and biologically possible is a third important consideration.

Potential Survival Change from HCP

Projecting survival changes associated with achieving the HCP survival goals depends on assumptions regarding historical passage survival through the projects. Little direct information on historical reach survival is available. Study groups released in the mid-1980's were used to calibrate a simple model of passage survival to estimates of annual arrival timing and spill at each project. Assuming base period survival rates of 86-88 % per project, achieving the HCP goals would increase average passage survival by 16-25% for steelhead, and by 21-35% for spring chinook (range is for 3-5 projects).[8]

For comparison purposes, we generated an estimate of what juvenile survivals may have been through the Mid-Columbia reach in the absence of the hydroelectric dams. PIT tag survival data from Snake River studies (e.g., Smith et al., 1998) were used to estimate downstream migration mortality rates for juvenile spring chinook and steelhead migrating through free flowing reaches

[8]Upper Columbia ESU's are more responsive to changes in passage survival at the series of mainstem dams due to the reliance on in-river migration since barging from McNary was curtailed in 1995.

within the Snake River system. The results were applied to each population grouping by multiplying the number of km from the tributary of origin to the Priest Rapids dam site against the per km survival rate from the Snake River studies. Estimated survivals to a point below the present Priest Rapids Dam varied from a low of .93 (Methow steelhead) to a high of .97 (Wenatchee River spring chinook). This range represents a 40% to 84% increase in survival over the base periods used in this analysis.

Summary: Potential Survival Improvements vs Requirements

The estimated improvements in passage survival associated with achieving the objectives expressed in the draft Mid-Columbia HCP are directly comparable to the life cycle survival improvement requirements generated by the historical analyses described above.

Spring Chinook

For spring chinook, meeting the HCP objectives would result in sufficient survival improvements to meet the projected needs under the assumption that future return per spawner patterns are represented by the 1960-94 brood year series with the possible exception of meeting IRL criteria for the Wenatchee (0 to 14% projected improvement needed after HCP contribution).

Projections based on the Wenatchee spring chinook data set indicate that even under the most optimistic scenarios modeled regarding future survival rates and the effectiveness of supplementation, additional survival improvements beyond those projected for draft HCP actions would be necessary to achieve extinction risk/recovery criteria if the conditions prevalent since 1980 continue. Under this scenario, an additional increase in life cycle survival of approximately 37% would be required to meet the 5% extinction risk threshold at 100 years. Increasing geometric mean escapements to IRL levels would require an additional survival improvement of 30 - 54%, depending upon assumptions and time frames.

Model runs based on the Methow data sets projected that the estimated survival improvements attained by meeting the proposed Mid-Columbia HCP objectives exceeded the required improvements to reduce direct extinction risks below the 5% level at 100 years under all three assumptions about future conditions. If future conditions are represented by the 1960-94 data series, achieving the survival improvements associated with the HCP criteria would also cover the improvements needed to meet IRL objectives. However, meeting the longer term IRL criteria at 48 or 100 years would require additional survival improvements beyond those associated with meeting the Mid-Columbia HCP passage objectives under the remaining future scenarios. Under the assumption that the relatively low return rates observed for 1980-94 broods are representative of the future, an additional survival improvements of 31-38%. Similar improvement levels would be required if 1970-94 is assumed as representative of future conditions.

Assuming the potential survival improvements associated with meeting the proposed HCP objectives would cover the projected improvements required to reduce direct extinction risks to below 5% at 100 years under the 1960-94 and the 1970-94 future scenarios. An additional improvement in life cycle survival of approximately 12 % would be required to meet the 5% extinction risk criteria under the more conservative 1980-94 projections. Achieving the survival improvements associated with the proposed HCP objectives would also meet IRL requirements under the assumption that 1960-94 population return per spawner rates are representative of the future. Using the 1970-94 series, an additional survival increment of 9-16% would be required to meet IRL levels. If 1980-94 data series is more representative of the average and range of future conditions, improvements of approximately 43-51% would be required to meet IRL targets at 100 years and 48 years, respectively.

Steelhead

For both of the modeled steelhead populations (the Wenatchee/Entiat and the Methow), gaining the survival improvements associated with meeting the proposed HCP objectives would cover the required changes for the 100 year extinction criteria only under the assumption that hatchery effectiveness was .25 or less. Model runs incorporating the .5, .75 and 1.0 effectiveness assumptions all project that additional improvements in survival would need to be realized to meet the 100 year risk criteria.

The model projections for both stock groupings indicate that survival improvements in addition to those corresponding to meeting the proposed HCP objectives would be needed to meet IRL levels under any of the assumptions regarding hatchery effectiveness.

Meeting Mid-Columbia HCP and FCRPS Objectives

The draft Federal Columbia River Power System Biological Opinion calls for implementation of an aggressive set of improvements to in-river survival at lower river projects effecting upper Columbia. The extent to which those improvements in survival represent a net increase in survival over the average for the 1980-92 base period used in this assessment is dependent upon assumptions regarding delayed mortality of transported fish[9]. The draft FCRPS Biological Opinion also characterizes the level of off-site mitigation by the federal action agencies given the continuing survival impacts of operating hydropower system.

Spring Chinook

Achieving the combined survival improvement increments associated with the proposed HCP and the FCRPS Biological Opinion (direct and off-site mitigation changes) would exceed the changes

[9]Before 1995, a portion of the smolt run arriving at McNary was collected and transported to below Bonneville Dam.

needed to meet the 100 year extinction risk criteria for all three stock groupings. The combination of improvements would also exceed the projected requirements to meet IRL objectives for the stocks with one exception: additional survival improvements would be needed to get the Wenatchee population to its IRL level of 3,750 spawners.

Steelhead

Again, assumptions regarding the relative effectiveness of hatchery origin fish in contributing to natural production have a significant impact on the results. The combined improvements from achieving the proposed HCP and FCRPS objectives would exceed the requirements to meet the 100 year extinction risk criteria for both stock groupings if hatchery effectiveness has been less than .50. Model runs based on the Wenatchee/Entiat data series also met this criteria under the assumption of .75 effectiveness. Additional survival improvements would be necessary to reduce the risk to 5% or less if hatchery effectiveness is assumed to be 1.0 (and at .75 in the case of the Methow data set).

Model runs representing both of the stock groupings indicate that survival improvement level needed to achieve IRL levels at 48 or 100 years would be met under the assumption that HCP and FCRPS survival improvements are fully realized. However, additional survival improvements over and above those associated with meeting HCP and FCRPS objectives would be needed to meet IRL levels if hatchery effectiveness is higher than .25.

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1 Introduction

The purpose of the Mid-Columbia QAR (Quantitative Analytical Report) process is to provide an assessment of the survival and recovery requirements of listed upper Columbia steelhead and spring chinook salmon. The report summarizes available information for these stocks, reviews alternative approaches to estimating extinction risks and recovery perspectives, and provides preliminary estimates of the relative risks of extinction under a range of alternative management and climate/environmental scenarios. A companion report, '*Upper Columbia River Steelhead and Spring Chinook Population Structure and Biological Requirements* (Ford, 2001), describes "...interim biological requirements for the recovery of Upper Columbia River spring chinook salmon and steelhead Evolutionarily Significant Units (ESU's).

While the report was initiated specifically to aid in reviewing proposed actions involving the Mid-Columbia hydroelectric projects, the information and analyses developed through the process should provide a starting point for assessing needed survival improvements in other areas. In addition to reducing the impact of hydroelectric projects, recovery of the upper Columbia listed populations will almost certainly require coordinated actions to address human induced impacts in habitat (up-river and estuarine areas), hatchery practices and harvest management.

The analyses summarized in this paper are intended to provide information on the following general questions:

1. What are the extinction risks for major populations comprising the upper Columbia steelhead and spring chinook salmon ESU's given a continuation of the management and environmental conditions associated with recent returns?

2. How are projected quasi-extinction risk indices affected by proportional increases in average spawner to spawner survival?

3. How would extinction risks and recovery probabilities be affected by implementation of actions called for in the draft Mid-Columbia Habitat Conservation Plan (HCP)[10]?

4. If necessary, what level of additional survival improvement would be needed to achieve survival and recovery objectives for these runs?

5. What is the projected combined effect of the actions called for in the draft Mid-

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[10]For the purposes of the QAR analyses, options were analyzed that assume that the survival goals set forth in the draft Mid-Columbia HCP would be met at all five of the mainstem hydroelectric projects in the mid-Columbia reach.

Columbia HCP and potential additional actions involving hydropower, habitat (tributary and estuarine), hatcheries, and harvest?

Future efforts will be aimed at refining and updating the analyses, specifically including assessments of the potential effects of alternative actions identified in each of the general categories - habitat, hydropower, hatcheries and harvest.

Background

Spring chinook salmon and steelhead populations originating in the upper Columbia River (confluence of the Yakima River upriver to Chief Joseph Dam) were recently listed under the Endangered Species Act (Busby, et al. 1996, Myers, et al. 1998). Populations of these species are currently found in the major tributaries entering the Columbia in this region including the Wenatchee, Entiat and Methow Rivers. The Okanogan River system is believed to have supported production of both species historically. Current production rates from the Okanogan are low relative to the other upper Columbia systems due largely to extensive habitat degradation (e.g., Mullen et al., 1992). Grand Coulee Dam, constructed in 1938, cut off access to production areas above the confluence with the Okanagan River. Chief Joseph Dam is also an anadromous block.

The Wenatchee and Entiat River systems begin as snowmelt from glaciers and snowfields on the slopes of the north Cascades. The Wenatchee system includes a major lake collecting inflow from several high gradient streams flowing off of the north Cascades. Both systems are characterized by sharply defined valleys and relatively high gradients (Mullan, et al, 1992). The Methow system also originates in the Cascades, but flows through a broad glacial valley. All three systems are influenced by similar climate conditions, although the Methow basin is likely more influenced by year to year drought and high temperature occurrences. Mullan et al (1992) estimates that the Wenatchee contains approximately 129 stream miles accessible to salmon and steelhead, the Entiat 46, and the Methow 182 accessible stream miles.

Mullan et al (1992) and Chapman et al (1994) summarize historical information on return levels of stocks to this region. Adult fish counts at Rock Island Dam, constructed in 1933, provide an index of total returns to the tributaries of the upper Columbia. Counts during the 1930's averaged approximately 2,500 spring chinook and 3,000 steelhead. These estimates were after substantial harvest in lower river fisheries. In addition to high harvest rates, upper Columbia fish runs were effected by substantial habitat degradation due to mining and grazing activities within the tributaries in the late 1800's and early 1900's. Habitat conditions are believed to have substantially improved over the last 100 years. Lower River harvest levels were reduced substantially in the 1970's, although steelhead harvest impacts in the upper Columbia region itself increased at the same time.

In the late 1930's and the early 1940's all spring chinook and steelhead entering the ladder at Rock

Island Dam were captured and they (or their progeny) were distributed among the upper Columbia tributaries below the Grand Coulee Dam site as part of the Grand Coulee Fish Maintenance Project (GCFMP). The effect of this effort on the native runs to the tributaries is still the subject of debate. Hatchery production, especially of steelhead, increased dramatically in the 1960's and 1970's. Steelhead runs have been predominately of hatchery origin since at least the early 1970's.

Returns of spring chinook increased through the 1980's, then dropped to extremely low levels in the mid-1990's. Steelhead returns showed a similar pattern, although the impact on natural runs is somewhat masked by hatchery production.[11]

A companion committee to this effort, the QAR Biological Requirements Workgroup, has reviewed and summarized available information on Columbia spring chinook and steelhead runs. The draft Biological Requirements Report concludes that:

"..there are (or historically were) three or four independent populations of spring chinook salmon in the upper Columbia River Basin, inhabiting the Wenatchee, Entiat, Methow and (possibly) Okanogan River Basins. There appears to be considerable population substructure within one or more of these major tributaries.....however, and this population substructure should be considered when evaluating recovery goals and management actions. Spring chinook spawning in Icicle Creek and Leavenworth National Fish Hatchery are an independent population, but this population is not considered part of the Upper Columbia spring chinook ESU (NMFS, 1999).

"..a reasonable interim recovery level is three independent, viable populations, one each in the Wenatchee, Entiat and Methow River basins....We defer discussion of goals for steelhead in the Okanogan to an Upper Columbia Recovery Team (QAR Biological Requirements draft, 1999).

[11]The analyses described in this report were based on data on returns through 1999. Return levels in 2000 and 2001 were high for both spring chinook and steelhead returns. Some prelimary analyses were included in this report to demonstrate the potential effect of including those returns on results of the analyses.

2 Historical Run Reconstructions

The population analyses described in this report are based on historical run reconstructions of the annual returns of spring chinook and steelhead originating from the upper Columbia River. The focus of the analysis is on natural production. Estimates of hatchery returns were included in the natural spawning escapement estimates in those cases where hatchery fish had the potential to stray and contribute to natural spawning. Run reconstructions for upper Columbia spring chinook populations begin with annual estimates of the number of spawning redds. Redd counts are not routinely made for steelhead because of environmental conditions at the time of spawning. For steelhead, run reconstructions are based on annual dam counts.

2.1 Spring Chinook

Spring chinook stocks in the upper Columbia have similar life history characteristics to spring chinook runs originating in the Snake River system. Adults begin returning from the ocean in the early spring, with the run into the Columbia River peaking in mid-May. Spring chinook begin entering the upper Columbia tributaries from April through July. After a prolonged holdover in freshwater, spawning occurs in the late summer, peaking in mid to late August (Chapman, et al, 1994). Juvenile spring chinook spend a year in freshwater before migrating to salt water in the spring of their second year of life. Most upper Columbia spring chinook return as adults after two or three years in the ocean. As a result, the adult run is dominated by four and five year old fish.

2.1.1 Reconstructions

Natural production of spring chinook from the Wenatchee, Entiat and Methow subbasins can be reconstructed from available information on spawning escapement, harvest, hatchery production and upstream passage survival. Unless noted, the reconstructions used in this assessment are from Beamesderfer et al, 1997. Annual returns of spring chinook to each of these tributaries are reconstructed beginning with estimates of spawning escapement based on redd surveys. Each years return is sequentially reconstructed by working backwards in time and (as appropriate) space from spawning escapement, adding in estimates of removals due to prespawning mortality, broodstock removal and harvest. Adult returns for each year are expanded outward to estimate the return to the mouth of the Columbia River.

Redd count information has been routinely collected in mid-Columbia tributaries since 1960 (e.g., Peven & Mosey, 1996, Schwartzberg and Rodger, 1986). Appendix table 1 (a,b,c) summarizes available redd counts and historical expansion factors to reflect coverage from non-index areas etc. for the Wenatchee, Methow and Entiat systems. Standardized index areas for spawning counts were established in all three tributaries in the early 1960's (Meekin, 1963). Index areas were established to include the primary spawning areas within each tributary (e.g., density of spawners/mile on Index reaches higher than on non-index reaches). The relative difference in densities between Index and Non-Index areas are accounted for in the expansion factors used to generate total system redd count estimates. In recent years, spawning ground surveys in the Wenatchee and the Methow River have been expanded so that virtually 100% of the available spawning area is surveyed each year.

Table 1: *Spring chinook spawning survey coverage by river system.*

System	Total Spawning Miles	Index Area Spawning Miles	Non-Index Area Spawning Miles
Wenatchee River	***84.7***	***46.1***	***38.6***
Entiat River	***13.9***	***6.8***	***7.1***
Methow River	***114.2***	***25.0***	***89.2***

Spawning ground surveys are conducted around the peak spawning period (late Aug. - Sept) in the upper Columbia tributaries. The areas surveyed are divided up into subreaches, the number of redds in each subreach are counted and tabulated by reach, keeping track of index areas and non-index subreaches separately. If the total Index area mileage is not surveyed, the average density per mile in the area surveyed is used to expand the Index area count to represent the full Index area. A total count for non-index reaches is generated by expanding from the non-index areas surveyed to the total non-index stream miles using the average non-index density per stream mile. Total redd counts for each system are generated by summing the corresponding index area and non-index area subtotals.

Expansion from redd count survey results to an annual estimate of the number of spawners in each tributary was accomplished by applying an estimated fish/redd ratio (2.2 fish per redd) calculated from Chiwawa redd count and weir count comparisons (see Beamesderfer et al., 1997). Spawning escapement estimates were expanded to tributary run size by adding in estimates of pre-spawning mortality (10% mortality rate), tributary sport catch (less than 5% harvest rate) and annual brood stocking removals for hatchery programs. Estimates of spawning escapements for more recent years (1996, 1997 and 1998) were generated using redd counts and the expansion factors for area and spawners/redd from Beamesderfer, et al., (1997).

Each of the upper Columbia tributaries has an associated set of hatchery production programs. Mitigation hatchery facilities are associated with each of the major tributaries (Wenatchee, Entiat and Methow). Returns from these programs can stray and contribute to natural spawning areas. Direct estimates of annual contributions from these programs to spawning escapements in natural areas are not available. Beamesderfer, et al., (1997) incorporated an assumed tributary specific stray rate into run reconstructions. With the exception noted below, the assumed stray rates are also incorporated into the following analyses. Run year returns were allocated to age group using age composition estimates derived from tributary specific sport fishery and hatchery escapement sampling. (See Beamesderfer, et al., 1997 for a more complete description of run reconstruction assumptions and techniques).

Estimated returns to the tributaries were expanded to account for mainstem losses and mainstem reservoir harvest rates to generate an estimated return to the Columbia River mouth. Beamesderfer et al. (1997) contains a more detailed description of the approach and calculations. Direct estimates of adults bound for upper Columbia tributaries are not available outside of the tributaries themselves. The run reconstructions summarized in the attached tables are based on the assumption that dam counts and estimates of harvest for the aggregate spring chinook and steelhead runs, respectively, can be used to estimate the annual impacts on individual component runs. This assumption is supported by the similarities in size and run timing among tributary runs of a particular race and species (in this case, spring chinook and A-run type steelhead). Given that assumption, losses between dams were estimated by comparing sequential dam counts and mainstem harvest rates were calculated as a simple function of the estimated harvest and the aggregate abundance of spring chinook in each reservoir. For each year, an interdam conversion rate was calculated by subtracting the estimated harvest and any 'turnoffs' assigned to a particular pool from the difference in upstream and downstream dam counts. Turnoffs would be estimates of the number of adults leaving the mainstem for hatcheries or tributaries associated with the particular pool.

Two changes to the approach described in Beamesderfer et al (1997) were implemented in developing the run reconstructions in this report. The previous run reconstruction used conversion rates for the upper Columbia reaches (McNary to Wells Dams) based upon dam counts including counts at Priest Rapids Dam. Given the strong evidence of substantial straying at Priest Rapids Dam of Ringold Hatchery fish (e.g., Lowell Sturenburg, draft report), an average per project conversion rate was calculated based on years with low Ringold Hatchery returns. That average was used to calculate annual reach survival estimates from McNary to each of the tributaries used in these analyses. The second change involved adjusting the estimated stray rates of hatchery returns into natural escapement areas within the Wenatchee and Entiat river systems. The assumed straying rate of Leavenworth Hatchery spring chinook was revised downward to 1% from the 5% applied in the analyses reported in Beamsdurfer et al (1997). This change is based on reports that only 1 Leavenworth tag has been recovered in several years of brood stocking and carcass sampling efforts in the Wenatchee River (Larry Brown, personal comm.). Given low natural returns in recent years, assuming a 5% stray rate results in a very high (>60%) estimate of hatchery composition on the spawning grounds. This conclusion does not seem reasonable given the lack of tag recoveries at the Chiwawa weir and on the spawning grounds. The analyses reported in the Beamsdurfer et al (1997) incorporated hatchery straying in the Entiat. The stray rate of Entiat National Fish Hatchery returns into natural spawning areas of the Entiat was

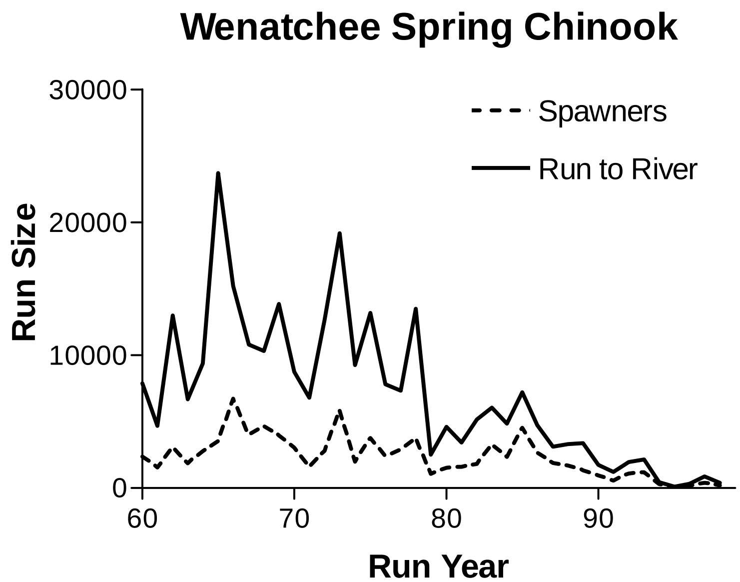

Figure 1 *Estimated annual return of Wenatchee origin spring chinook (excluding Icicle Creek & Leavenworth Hatchery)..*

assumed to range from 20% in the 1970's to 10% in later years. Carcass sampling in the natural spawning areas within the Entiat has also failed to find cwt evidence for straying (e.g., Carie ,1999). The assumed stray rate of hatchery returns in the Methow River (25% of hatchery rack returns to the Winthrop Hatchery) was included into the analysis, given cwt recoveries on the spawning grounds in recent years.

Recent average (5 year) harvest rates and mainstem conversion rates were used to expand the 1996, 1997 and 1998 spawning escapement estimates. Year specific estimates are being developed as part of regional efforts. Those estimates will be incorporated into future QAR analyses. Figure 1 illustrates the recent trend in return to the river and spawning escapement for up-river spring chinook stocks.

2.1.2 Brood Year Reconstructions

Annual returns of spring chinook to the upper Columbia are summarized in Appendix tables (2 a,b,c). For each year, the estimated spawning escapement is expanded to run to the Columbia River mouth using the assumptions described above. Annual estimates of age composition are available for years after 1973. Those estimates are used to break out each years annual return by age. The sequential set of annual run sizes allocated by age is used as the basis for reconstructing total returns from each spawning escapement in the annual series. The production from each spawning escapement is estimated by summing up the subsequent returns from that particular spawning escapement across the appropriate range of future years. For comparison, the series was extended back to incorporate return rates from spawning in the 1960's by applying average age composition to return years prior to 1973. The analyses described below all start with the basic reconstruction of a series of spawner - return pairs for each subbasin.

2.1.3 Cohort Analyses

Estimates of brood year escapement and adult returns are used to construct a basic cohort analysis for the target stocks. The production resulting from each brood year is summed across years of return. Under this approach, the total production from each brood year considered in the analysis was reconstructed starting from the oldest year of return in the database (usually age 5 measured from spawning year). An estimate of the number of fish of originating from a particular spawning year alive in the ocean at the beginning of age 5 is calculated by dividing the corresponding age 5 return to the Columbia by an estimate of ocean survival between the beginning of age 5 and the return to the Columbia of that component. The number of fish from that brood cycle alive at the beginning of age 4 is calculated by adding the estimated number of fish at the beginning of age 5 to the estimated age 4 return of that particular brood year and dividing that total by an estimate of age 4 ocean survival. The series is continued backwards to the beginning of age 2. Ocean survival at age assumptions used by the Chinook Technical Committee of the Pacific Salmon Commission (Anon., 1991) were used in the analysis (survival rates of .9, .8, and .7 corresponding to survival to ages 6, 5, and 4). The results of the cohort analysis are useful in calculating additional population parameters. Annual rates of maturity by age can be calculated from the cohort reconstructions. The maturity rate for a given age (I) and brood year (y-I) is estimated by dividing the number of adult returns of age (I) in year (y) by the corresponding ocean cohort size (number of fish from brood year (y-I) estimated as alive in the ocean in year (y) before migration to the river). Cohort reconstruction results, in combination with smolt production estimates, can be used to develop a time series of smolt to adult survival rates.

Smolt to Adult Survivals

Smolt to adult survival estimates for each brood year in the analysis were derived by dividing the estimated number of adult fish alive at the beginning of age 2 by the estimated number of out migrating smolts from the parent escapement.

This rate as calculated through the cohort analysis should be thought of as an index of first year survival. At this point the model incorporates a constant egg-smolt survival rate. Any changes in that constant or going to a more complicated model would likely change the absolute value of the estimated S2s.

2.1.4 Return per Spawner Results

Historical return per spawner estimates are included in each of the population specific cohort reconstructions (table 1a,b,c). The simple extinction risk analyses described below are based on spawner to spawner return rates (Figures (2,3,4). Brood year return ratios were expressed in terms of age 4 and older fish at spawning. The data were adjusted to reflect changes in two major factors: harvest and the number of mainstem dams between each river and the ocean. Harvest rates on spring chinook declined significantly in the early 1970's (cohort tables and Fig.1). For the purposes of the simple extinction analysis, return levels for brood years prior to 1974 were adjusted to reflect recent average harvest rates. Return levels were also adjusted to reflect the construction of mainstem dams coming on line in the 1960's by adjusting historical returns w downwards by 15% per project for years prior to the construction of each dam.

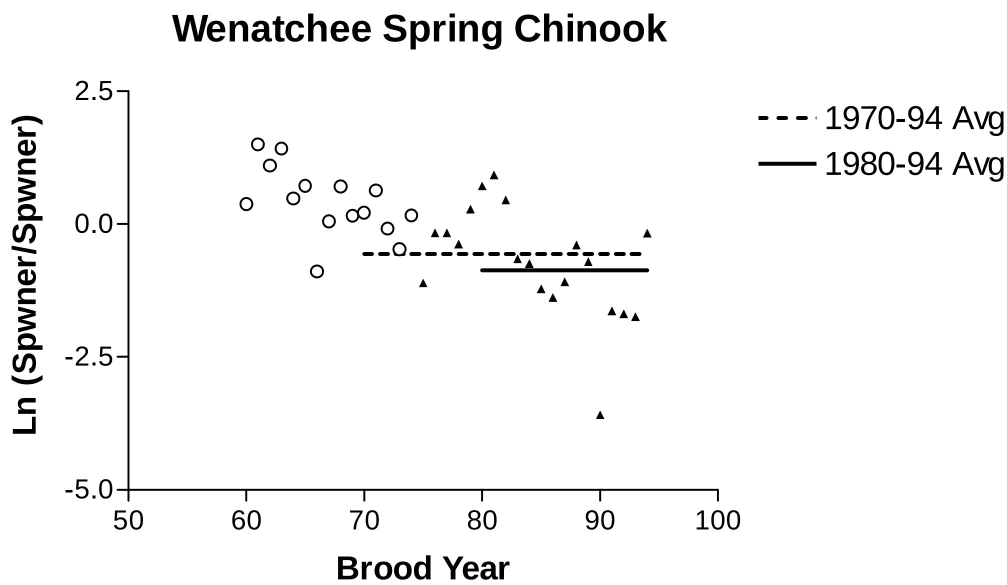

Figure 2 *Wenatchee spring chinook. Natural log ratio of returning spawners to parent spawners. Open circles: adjusted to reflect recent average harvest rates.*

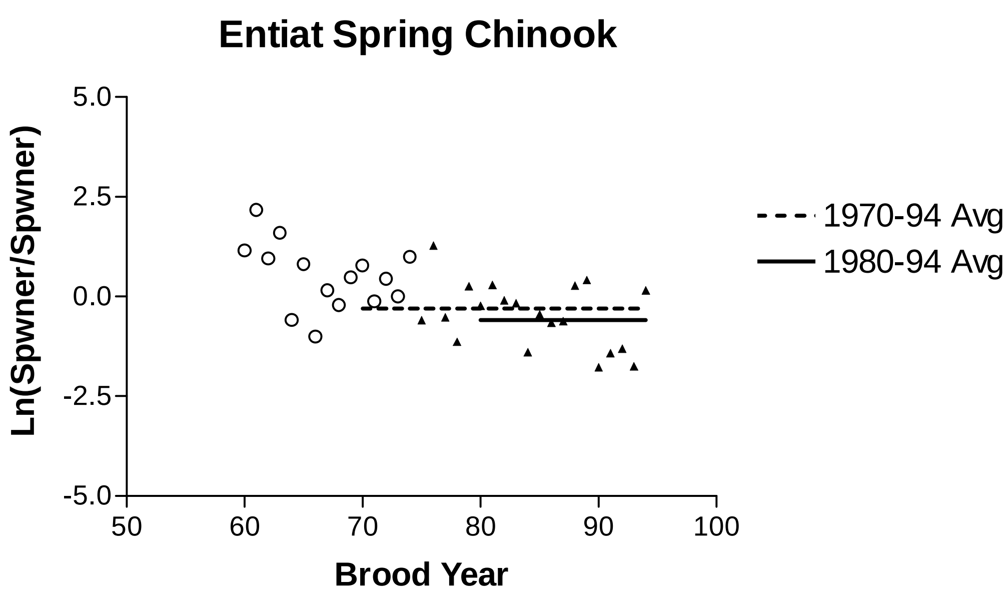

Figure 3 *Entiat Spring chinook run. Natural log of the ratio of returning spawners to parent spawners. Open circles: adjusted to reflect recent average harvest rates.*

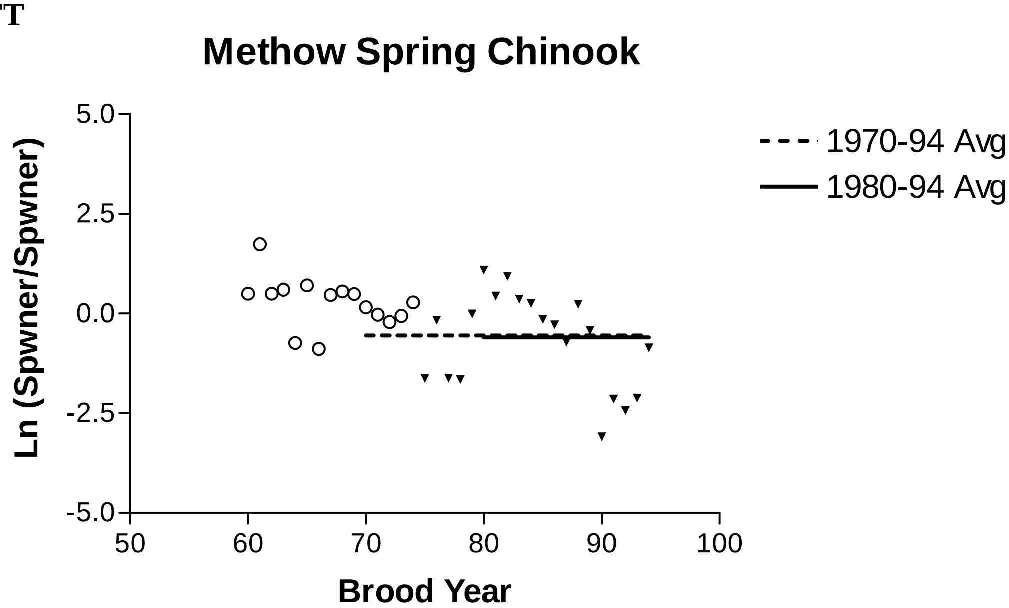

Figure 4 *Methow spring chinook run. Natural Log ratio of returning spawners to parent spawners. Open circles: adjusted to reflect recent average harvest rates.*

Returns from each brood year spawning escapement were estimated by breaking each return down by age through application of year specific age composition estimates obtained from spawning ground surveys, tributary fishery samples or corresponding hatchery returns. Annual age composition estimates were not available prior to the 1970's, averages from the later years were applied. Return levels were relatively consistent during the 1960's, applying the average age composition may have introduced relatively little error.

Patterns in the resulting return/spawner data were primarily determined by the redd count results. Those data were collected independently for each drainage. Temporal patterns in the three tributary data sets are similar - relatively high return per spawner estimates for the early 1960's with consistent multi-year peaks in the mid-1970's and the early/mid 1990's, followed by a sudden decline in brood year 1990 to extreme low values. Return/spawner estimates remained very low for 2-3 brood years. The last year estimated, brood year 1994, appears to significantly higher than the low levels immediately preceding. The similarities in pattern among the three stocks is reflected in high correlation coefficient (.77 for the Wenatchee/Methow pair and the Wenatchee/Entiat pairing, .71 for the Methow/Entiat comparison).

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Table 2: *Adult (Age 4+) Spawner to Spawner return estimates for upper Columbia Spring Chinook Stocks. Detailed run reconstructions are provided in Appendix A. Return levels for brood years marked with asterisks (1960-69) adjusted to reflect recent historical average harvest rates, number of mainstem dams. Returns from 94 brood escapements include components based on jack returns. See text for further descriptions.*

BroodYear	**Wenatchee Spring Chinook**			**Entiat Spring Chinook**			**Methow Spring Chinook**		
	Spwrs	**Return**	**R/S**	**Spwrs**	**Return**	**R/S**	**Spwrs**	**Return**	**R/S**
*60	2,057	2,535	1.23	316	815	2.58	2,006	2,740	1.37
*61	1,428	4,060	2.84	127	428	3.36	616	2,396	3.89
*62	2,685	4,652	1.73	315	772	2.45	2,472	3,423	1.38
*63	1,114	3,645	3.27	269	660	2.46	1,245	1,978	1.59
*64	2,538	3,821	1.51	1,096	589	0.54	3,845	1,551	0.40
*65	2,526	2,990	1.18	232	323	1.39	1,115	1,405	1.26
*66	5,836	1,866	0.32	831	236	0.28	4,280	1,417	0.33
*67	3,283	1,933	0.59	648	293	0.45	2,163	1,384	0.64
*68	4,064	3,821	0.94	685	330	0.48	1,707	1,805	1.06
*69	3,730	3,673	0.98	391	516	1.32	1,323	1,752	1.32
*70	2,530	2,677	1.06	182	330	1.81	1,525	1,496	0.98
71	1,302	2,675	2.05	348	335	0.96	1,258	1,340	1.07
72	2,657	2,113	0.80	182	218	1.20	1,569	978	0.62
73	5,225	3,114	0.60	636	667	1.05	2,152	2,120	0.99
74	1,939	2,442	1.26	267	756	2.83	1,163	1,684	1.45
75	3,548	1,169	0.33	458	254	0.55	1,987	390	0.20
76	1,692	1,438	0.85	81	292	3.61	390	330	0.84
77	2,648	2,238	0.85	501	297	0.59	1,841	363	0.20
78	3,733	2,559	0.69	1,009	322	0.32	2,541	488	0.19
79	1,009	1,333	1.32	233	300	1.28	462	458	0.99
80	1,414	2,898	2.05	295	233	0.79	348	1,029	2.96
81	1,561	3,919	2.51	285	381	1.34	442	683	1.54
82	1,744	2,753	1.58	322	291	0.90	528	1,335	2.53
83	3,158	1,639	0.52	324	273	0.84	818	1,175	1.44
84	2,211	1,049	0.47	250	62	0.25	868	1,124	1.29
85	4,408	1,300	0.29	351	222	0.63	1,204	1,039	0.86
86	2,614	655	0.25	321	165	0.52	891	677	0.76
87	1,834	616	0.34	194	104	0.54	1,449	711	0.49
88	1,656	1,112	0.67	201	265	1.31	1,588	2,004	1.26
89	1,306	641	0.49	112	170	1.51	1,086	708	0.65
90	913	25	0.03	254	43	0.17	1,089	49	0.05
91	521	102	0.19	93	22	0.24	481	56	0.12
92	1,063	197	0.18	129	35	0.27	1,598	140	0.09
93	1,177	205	0.17	311	54	0.17	1,344	161	0.12
94	270	***198***	***0.73***	73	**85**	**1.16**	276	**116**	**0.42**

An examination of return/spawner by brood year series indicated that high and low values appear to occur in series - a low return/spawner is more likely to be followed the next year by another low, high values are generally more likely to be followed by another high value. Statgraphics statistical routines were used to evaluate the basic distribution of return/spawner rates and to determine the statistical significance of year to year correlations in rates. Significant autocorrelation at a lag of 1 year was detected in the time series (fitted coefficient outside of 95% confidence limits for 0.0 correlation). A simple correlation model (Rick Deriso, personal communication) was used to incorporate year to year correlation into the Cohort Return Rate (CRR) model. Details of the model are provided in the model description section below.

Table 3: *Statistical analysis of spawner to spawner ratios for alternative base periods for Upper Columbia spring chinook data sets.*

Population	**Period (Brd. Yrs)**	**Results of Statistical Analysis**		
		Mean (ln)	**Std. Dev. (ln)**	**Std. Error (ln)**
Wenatchee	***1980-94***	-.863	1.138	.294
	1970-94	-.569	0.992	.198
	1960-94	-.239	1.047	.180
Entiat	***1980-94***	-.586	.770	.333
	1970-94	-.308	.821	.220
	1960-94	-.055	.949	.184
Methow	***1980-94***	-.595	1.290	.199
	1970-94	-.563	1.101	.164
	1960-94	-.285	1.090	.160

In recent years theories regarding the potential effect of factors associated with climate/environmental cycling have gained a lot of attention (e.g., Mantua, et al.,1997). In particular, associations between an index of north pacific oceanographic/atmospheric conditions, the Pacific Decadal Oscillation index, and salmon production has been postulated. The PDO is characterized by a 30 year cycle, with a major change from positive to negative conditions in the mid 1970's. No clear corresponding pattern is apparent in the upper Columbia spring chinook series. The observed year to year variation in return per spawner rates for upper Columbia spring chinook stocks are affected by a number of factors operating on the in stream and ocean environment. The available time series (late 1950's to the present) for upper Columbia Spring chinook barely encompasses one potential cycle. From a statistical perspective, a time series extending over several cycles would be required to evaluate potential relationships between productivity and climate/environmental patterns.

2.1.5 Smolt per Spawner Analysis

A simple linear smolt production model was used for the initial modeling of upper Columbia spring chinook runs. Very little direct information on egg-smolt survival has been collected from upper Columbia Spring chinook. The model was fit to a data series of redd counts paired with subsequent estimates of parr production for the Chiwawa River, a tributary to the Wenatchee (Table 4). The resulting average estimate of egg to smolt survival was used to partition the estimated survival from egg to adult into life stage components.

Table 4: *Parr and smolt production estimates from Chiwawa River data (Tracy Hillman, personal communication).*

Year	**Redds**	**Eggs (4,600 egg/fm)**	**Parr**		**Smolts (@ 40% overwinter survival)**		
			Parr	**Egg-Parr.**	**Smolts**	**Smlt/Spnr**	**Egg-Smlt**
1991	104	478,400	45,483	.095			
1992	302	1,389,200	79,113	.057	39,727		.029
1993	106	487,600	55,056	.113	8,662		.018
1994	82	377,200	44,240	.117	16,472		.044
1995	13	59,860	5,815	.097	3,830		.064
1996	23	105,860	16,066	.152	16,978		.160
1997	82	377,260	68,415	.181	-		
	Regression Est.			***.122***			**.048**

Adult spawner counts were estimated from redd counts. Parr production (age 0+) was estimated from field surveys in the late summer of the second year following spawning. Smolt production estimates were also made from weir counts. Given the likelihood that some unknown portion of the parr production from a particular brood year emigrated below the weir outside of the counting period, a standard overwintering survival of .40 (Larry Brown, WDFW, personal communication) was used for the analysis. For the purposes of the analyses described below, average values were assumed to apply to each brood year. Annual variability in overwintering survival can be quite high (T. Hillman, personal communication). Smolt production per spawner for each year in a historical series was generated through a simple algorithm:

1. Egg production was calculated by multiplying the estimated number of spawners in each age class by the corresponding fecundity (eggs/female) and percent female estimates.

2. Egg to parr and egg to smolt survival rates were calculated for each historical pair.

3. An average parr/spawner estimate was estimated by a regression of parr production on egg disposition. The 1992 data point was excluded, due to the high level of spawners relative to carrying capacity (L. Brown personal communication).

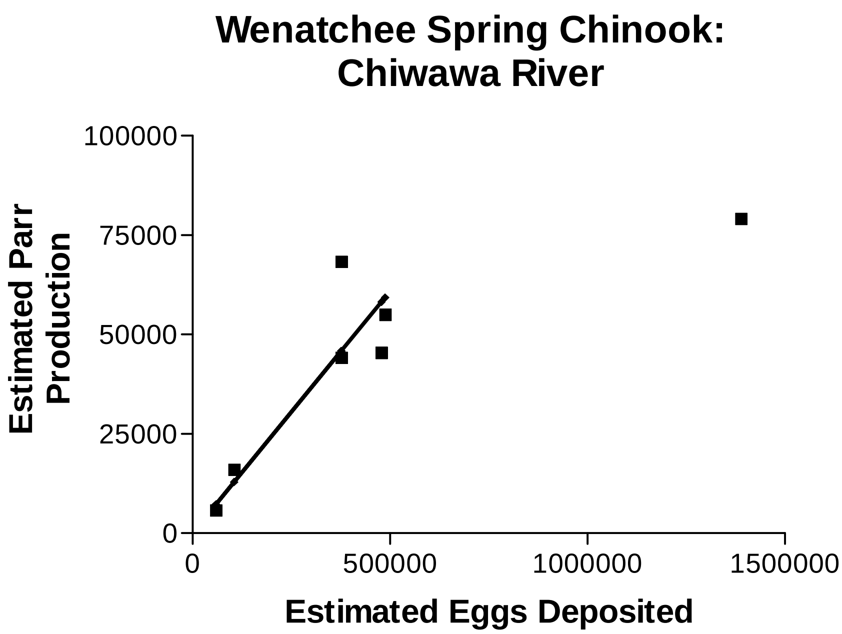

Figure 5 *Parr production as a function of estimated egg deposition: Chiwawa River data set (Tracy Hillman, personal communication. Fitted line = regression excluding 1992 point.*

Chapman (1994) summarizes available information on egg to parr and egg to smolt survival rates for various Columbia River tributaries. Although egg to parr survival rates are typically highly variable, the estimates as calculated above are within the range reported in other studies for Snake and Columbia River systems. The survival rate derived from the Chiwawa data set is consistent with estimated survival rates derived from studies in the Yakima, Deschutes and John Day river systems (average of 5.7% survival from egg to smolt). Estimates of egg deposition and subsequent smolt production have been reported for the Tucannon River (Bumgarner et al., 1997). The average egg-smolt survival corresponding to the Tucannon data set for brood years 1985-94 was 4.7%.

2.2 <u>Steelhead</u>

The life history patterns of upper Columbia steelhead are complex. Adults return to the Columbia River in the late summer and early fall; most migrate relatively quickly up the mainstem to their natal tributaries. A portion of the returning run overwinters in the mainstem reservoirs, passing over the upper mid-Columbia dams in April and May of the following year. Spawning occurs in the late spring of the calendar year following entry into the river. Juvenile steelhead spend one to seven years rearing in freshwater before migrating to the ocean. Smolt outmigrations are predominately age 2 and age 3 juveniles. Most adult steelhead return after one or two years at sea, starting the cycle again.

2.2.1 Reconstructions

Estimates of the annual returns of upper Columbia steelhead populations are based on dam counts. Cycle counts are used to accommodate the prevalent return pattern in up-river summer steelhead (runs enter the Columbia in late summer and fall, some fish overwinter in mainstem reservoirs - migrating past the upper dams prior to spawning the following spring). Counts over Wells Dam are assumed to be returns originating from natural production and hatchery outplants into the Methow and Okanogan systems. The total returns to Wells Dam are calculated by adding annual brood stock removals at Wells to the dam counts. The annual estimated return levels above Wells Dam are broken down into hatchery and wild components by applying the ratios observed in the Wells sampling program for run years since 1982 (Appendix table B1). The focus of the following analytical work is on returns from 1980 to the present. The series was extended back to cycle year 1975/76 to capture brood year escapements and juvenile migrations resulting in returns after 1980.

Harvest estimates for upper Columbia reservoirs and tributaries are generated by expansion from angler punch card returns (Figs. 6&7, data from L. Brown, WDFW). Punch card expansions for relatively small areas such as those of interest in this study are subject to high levels of sampling error - annual catch estimates are extrapolated from relatively small sample of anglers. To reduce the potential impact of such error on the extinction analyses described below, a three year running average (weightings of .25, .5 and .25) was applied to smooth the estimates. Harvest rates developed in the run reconstructions are based on the assumption that reported harvest after 1985 reflects hatchery catches only. Associated losses of wild fish due to handling/release mortalities are incorporated by assuming that wild fish are hooked at the same rate as hatchery fish with a 10% mortality after release. In addition to losses due to harvest, a 10% prespawning mortality rate is assumed to apply.

Rock Island Dam is downstream of Wells Dam and the Wenatchee and Entiat subbasins. An estimate of the annual composite returns to the Wenatchee/Entiat can be derived by subtracting reservoir harvest and brood stocking removals from the difference between the Rock Island and Wells dam counts. The differences are calculated for hatchery and wild runs, respectively. For cycle years since 1985/86, annual Rock Island counts are divided into hatchery and wild components based on ratios estimated from the Priest Rapids sampling effort (Brown, 1995). Hatchery/wild breakouts for the 1982/83 through the 1984/85 cycle years are based on a regression of the Priest Rapids estimates on the Wells estimates. An average was applied to generate breakouts for earlier years. Punch card estimates of harvest are used to generate annual harvest rate estimates as described above.

An alternative approach was considered that used Rocky Reach counts to split off the Entiat run from the Wenatchee. That approach was not used for the analyses for two reasons: the lack of hatchery wild breakouts at Rocky Reach Dam and inconsistencies generated between tributary estimates because of differences in dam counts.

Summer steelhead returning to the upper Columbia are impacted by fisheries and dams below

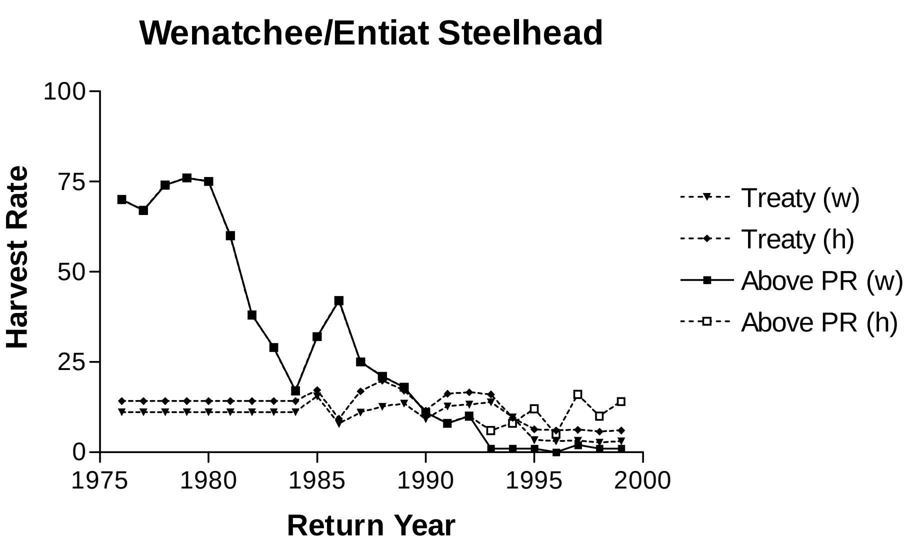

Figure 6 *Columbia River fishery harvest rates. Mainstem Treaty harvest rate from U.S. v Oregon TAC Reports. Upriver harvest rates based on WDFW punch card return data. Catch/Release mortality assumed at 10%*

Rock Island. Upstream passage losses were accounted for by assuming a loss of 3% at each mainstem hydroelectric project. Annual harvest impacts were generated for the aggregate summer steelhead return to the Columbia River using the general approach described in Chapman et al.,

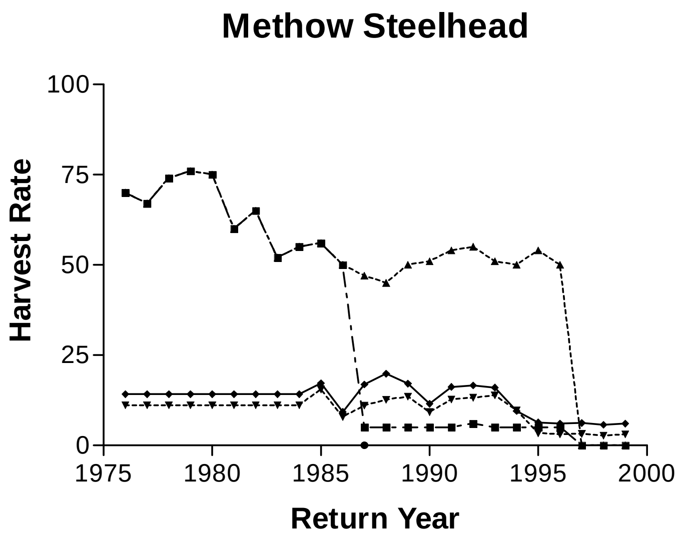

Figure 7 *Columbia River fishery harvest rates. Mainstem Treaty harvest rate from U.S. v Oregon TAC Reports. Upriver harvest rates based on WDFW punch card return data. Catch/Release mortality assumed at 10%.*

(1994), Brown (1995) and Mullan et al (1992). Reported harvest in the lower river for both sport (punch card estimates from Washington and Oregon) and commercial harvest (WDFW, 1999) were summed and divided by the estimated run over Bonneville Dam. A zone 6 tribal harvest rate was calculated in a similar manner. The resulting set of annual harvest rates was assumed to apply to all components of the run returning to the upper Columbia.

2.2.2 Brood Year Reconstructions

Each annual run of upper Columbia steelhead consists of returns from several spawning years. The total return from each spawning year can be reconstructed by breaking each years return down into components by age and summing those components by brood year (across return years). The annual return estimates described above were partitioned by age using age estimates obtained from the Wells and the Priest Rapids sampling programs (e.g., Brown, 1995). Age sampling was available for return years 1986-97. The average age composition for 1986-97 was used for those years (1976-85) for which no sampling data were available. Break-downs were done separately for hatchery and wild returns, reflecting the differences in age distribution between the two groups. A brood year summary for wild returns is in Table A4.

2.2.3 Cohort Analyses

Basic population parameters for the upper Columbia steelhead run were derived from the brood year reconstruction tables using cohort analysis (see general description under Spring Chinook section). There is little direct information on annual ocean survival rates for steelhead. Given their similarity in size to other salmon, the basic survival at age assumptions used by the Chinook Technical Committee of the Pacific Salmon Commission were used in the analysis (survival rates of .9, .8, and .7 corresponding to survival to ages 6,5, and 4). It is generally believed that the majority of ocean mortality and therefore the bulk of year to year variation in ocean survival for salmonids occurs in the first few months of ocean life. Deviations from this pattern in the actual data sets are transferred to the estimated outmigrant smolt to adult mortality in the simple models used in these analyses.

The results of the cohort analysis are useful in calculating two additional population parameters – the rate of maturity by age and an estimate of survival from spawner or smolt to adult. Age specific maturation rates are calculated as the proportion of the estimated number of adults alive at a given age that return to the Columbia at that age.

2.2.4 Return per Spawner Results

Adult Return/Spawner estimates were calculated for two components of the Upper Columbia River steelhead run, the Wenatchee/Entiat return and the above Wells return. The Wenatchee/Entiat populations were modeled as a single aggregate group given the difficulties in separating estimated returns to the two subareas (see run reconstruction section above for discussion of problems). Natural production from above Wells was assumed to be from the Methow basin. Hatchery returns above Wells Dam were apportioned to the Methow and the Okanogan basins based upon release ratios. In most years approximately 1/3 of the steelhead smolt releases were into the Okanogan basin.

Hatchery returns predominate the estimated escapement in both instances. The effectiveness of hatchery spawners relative to their natural counterparts is a major uncertainty for both populations. Hatchery effectiveness can be influenced by at least three sets of factors: relative distribution of spawning adults, relative timing of spawning adults, and relative effectiveness of progeny. No direct information is available for the upper Columbia stocks. Outplanting strategies have varied over the time period the return/spawner data were collected (1976-94 brood years). While the return timing into the Columbia River is similar for both wild and hatchery steelhead returning to the upper Columbia, the spawning timing in the hatchery is accelerated. The long-term effects of such acceleration on the spawning timing of returning hatchery produced adults in nature is not known. We have no direct information on relative fitness of upper Columbia progeny with at least one parent of hatchery origin.

Assumptions regarding the historical relative effectiveness of hatchery returns spawning in the wild can have a significant effect on estimates of population productivity. As a result of this uncertainty, population parameters were developed for a range of possible relative hatchery effectiveness values and extinction risk assessments were carried out under each alternative. Relative Hatchery Effectiveness values of .25, .5, .75 and 1.0 were analyzed. Estimated wild production from each brood year remains fixed in these analyses. For each assumed effectiveness, the number of spawners producing each natural cohort is calculated as a simple weighted average, applying one of the four discounting values to the estimated number of hatchery spawners for each year in the series.

Aggregate (hatchery plus wild) adult steelhead return levels to the spawning grounds have ranged above estimated carrying capacity in some recent years - both as a result of high hatchery contributions and occasional high survival years. For the purposes of fitting the average return per spawner model, only brood years whose escapements were below the estimated carrying capacity thresholds for each respective population were used in estimating the average return per spawner rate for the series.

The results of applying these assumptions to the upper Columbia steelhead historical return per spawner data are compiled in Table 5 (a&b) and illustrated in Figs.8 and 9.

Table 6 summarizes the statistics derived from the 1976-92 historical brood year spawner to spawner series. The geometric mean R/S (spawner to spawner) is an estimate of the median growth rate of the population. A value of .75 means that returns from a particular spawning would be expected to be only 75% of parental stock size. Values less than 1 indicate a strong rate of decline. Positive values indicate that the population is growing, but there still may be significant risks of extinction due to near to year variations in return rates. Assumptions regarding hatchery effectiveness have a strong effect on the estimated population growth rate.

Table 5a: *Recent historical Return (estimated run to spawning grounds) per spawner estimates for Wenatchee/Entiat Steelhead as a function of a range of possible values for the relative contribution of hatchery spawners to smolt production.*

Wenatchee/Entiat Steelhead					Heff = 1.0	2700	Heff=0.75		Heff=0.50		Heff=0.25	
Brood Year	Hatchery	Natural	Adjusted Natural Returns	Brood Year Natural Returns	Spawners	R/S	Spawners	R/S	Spawners	R/S	Spawners	R/S
1976	1,033	312	***573***	***553***	1,345	0.41	1,087	0.51	828	0.67	570	0.97
1977	1,642	477	***708***	***568***	2,119	0.27	1,708	0.33	1,298	0.44	887	0.64
1978	728	197	***251***	***685***	925	0.74	743	0.92	561	1.22	379	1.81
1979	1,321	357	***565***	***899***	1,678	0.54	1,348	0.67	1,018	0.88	687	1.31
1980	1,100	284	***557***	***1,127***	1,384	0.81	1,109	1.02	834	1.35	559	2.02
1981	1,102	347	***519***	***1,375***	1,449	0.95	1,173	1.17	898	1.53	622	2.21
1982	1,470	527	***714***	***1,605***	1,996	0.80	1,629	0.99	1,262	1.27	894	1.79
1983	5,176	781	***980***	***1,472***	2,700	0.55	2,700	0.55	2,700	0.55	2,075	0.71
1984	4,763	945	***1,067***	***1,974***	2,700	0.73	2,700	0.73	2,700	0.73	2,136	0.92
1985	6,610	1,646	***1,782***	***1,121***	2,700	0.42	2,700	0.42	2,700	0.42	2,700	0.42
1986	5,107	1,287	***1,436***	***790***	2,700	0.29	2,700	0.29	2,700	0.29	2,564	0.31
1987	3,109	2,286	***2,256***	***659***	2,700	0.24	2,700	0.24	2,700	0.24	2,700	0.24
1988	2,132	1,152	***1,141***	***1,024***	2,700	0.38	2,700	0.38	2,218	0.46	1,685	0.61
1989	660	1,061	***1,065***	***507***	1,721	0.29	1,556	0.33	1,391	0.36	1,226	0.41
1990	1,276	604	***596***	***503***	1,880	0.27	1,561	0.32	1,242	0.41	923	0.55
1991	779	851	***860***	***423***	1,630	0.26	1,435	0.29	1,241	0.34	1,046	0.40
1992	2,720	840	***834***	***504***	2,700	0.19	2,700	0.19	2,200	0.23	1,520	0.33
1993	606	448	***450***	***515***	1,054	0.49	903	0.57	751	0.68	600	0.86
1994	1,558	474	***471***	***514***	2,032	0.25	1,642	0.31	1,253	0.41	864	0.60
1995	1,157	659	***657***	***553***	1,816	0.30	1,527	0.36	1,237	0.45	948	0.58
1996	1,487	371	***369***	***588***	1,858	0.32	1,486	0.40	1,114	0.53	743	0.79
1997	**2,972**	**529**	***529***									
1998	**1,290**	**506**	***506***									
1999	**2,096**	**590**	***590***									

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Table 5b: *Recent historical Return (estimated run to spawning grounds) per spawner estimates for Methow Steelhead as a function of a range of possible values for the relative contribution of hatchery spawners to smolt production.*

	Methow Steelhead				Heff = 1.0	2200	Heff=0.75		Heff=0.50		Heff=0.25	
Brood Year	Hatchery	Natural	Adjusted Natural Returns	Brood Year Natural Returns	Spawners	R/S	Spawners	R/S	Spawners	R/S	Spawners	R/S
1976	630	125	396	309	755	0.41	597	0.52	440	0.70	282	1.09
1977	825	164	467	322	988	0.33	782	0.41	576	0.56	370	0.87
1978	177	35	126	318	212	1.50	168	1.90	124	2.58	79	4.01
1979	404	80	322	285	484	0.59	383	0.74	282	1.01	181	1.57
1980	376	75	288	356	451	0.79	357	1.00	263	1.35	169	2.11
1981	746	148	351	502	894	0.56	707	0.71	521	0.96	334	1.50
1982	963	120	325	498	1,083	0.46	842	0.59	601	0.83	360	1.38
1983	4,631	109	217	380	2,200	0.17	2,200	0.17	2,200	0.17	1,267	0.30
1984	3,675	168	356	598	2,200	0.27	2,200	0.27	2,006	0.30	1,087	0.55
1985	4,190	336	725	478	2,200	0.22	2,200	0.22	2,200	0.22	1,384	0.35
1986	3,235	179	340	445	2,200	0.20	2,200	0.20	1,796	0.25	987	0.45
1987	1,297	592	590	415	1,888	0.22	1,564	0.27	1,240	0.33	916	0.45
1988	1,070	404	386	551	1,475	0.37	1,207	0.46	939	0.59	672	0.82
1989	1,011	513	487	175	1,524	0.11	1,271	0.14	1,019	0.17	766	0.23
1990	829	407	386	119	1,236	0.10	1,029	0.12	821	0.14	614	0.19
1991	1,604	712	674	87	2,200	0.04	1,916	0.05	1,515	0.06	1,113	0.08
1992	1,485	321	303	127	1,806	0.07	1,435	0.09	1,064	0.12	692	0.18
1993	536	157	149	195	693	0.28	559	0.35	425	0.46	291	0.67
1994	512	117	112	193	630	0.31	502	0.38	374	0.52	246	0.78
1995	195	100	94	300	294	1.02	246	1.22	197	1.53	148	2.03
1996	976	224	212	372	1,199	0.31	955	0.39	712	0.52	468	0.80
1997	2,002	88	88									
1998	1,463	215	215									
1999	1,577	377	377									

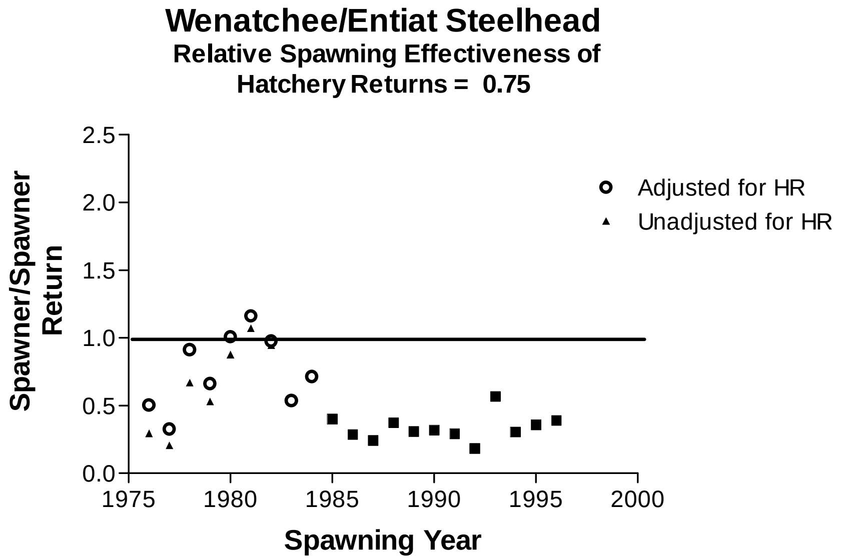

Figure 8 *Ratio of returning spawners to parent spawner estimates as a function of assumed hatchery spawner effectiveness. Pre-1985 values adjusted to reflect recent average natural returns harvest rate.*

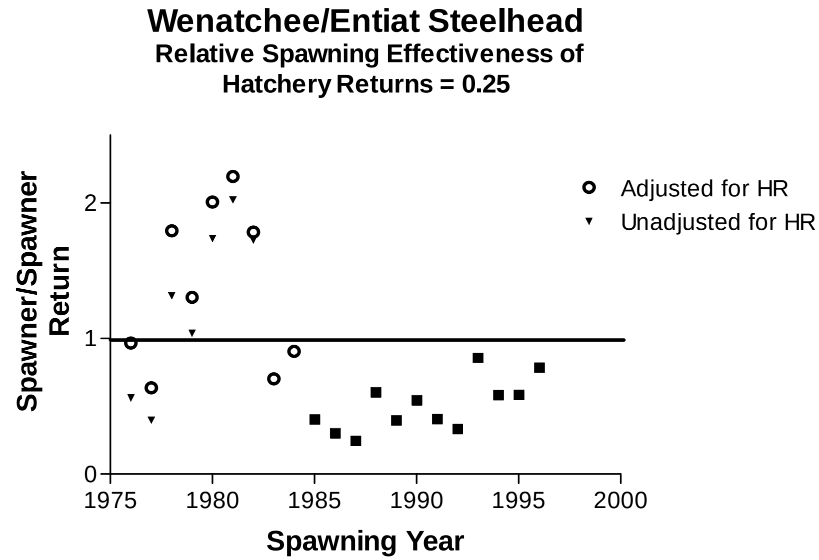

Figure 9 *Ratio of returning spawners to parent spawner estimates as a function of assumed hatchery spawner effectiveness. Pre-1985 values adjusted to reflect recent average natural returns harvest rate.*

Table 6: Upper Columbia Steelhead**:** *Estimated return per spawner (R/S) as a function of the relative effectiveness of hatchery returns as spawners.*

Upper Columbia Steelhead		**Relative Effectiveness of Hatchery Origin Spawners to Natural Origin Spawners.**			
		0.25	**0.50**	**0.75**	**1.00**
Wenatchee/ Entiat (1976-94 broods)	***Geomean R/S***	***1.10***	***.78***	***.61***	***.50***
	Ln(s/s)	.098	-.243	-.494	-.693
	Stnd Dev.	1.103	.573	.540	.520
Methow (1976-94 broods)	***Geomean R/S***	**.83**	**.54**	**.40**	**.32**
	Ln(s/s)	.916	-.611	-.907	-1.135
	Stnd Dev.	.832	.854	.404	.805

2.2.5 Smolt per Spawner Analysis

Smolt production per spawner estimates for upper Columbia tributaries have been developed using results from the smolt counting project at Rock Island Dam (e.g., Peven & Hays, 1989). Table 7 summarizes hatchery and natural smolt production estimates for the production areas contributing to the Rock Island dam counts. The smolt migration through Rock Island dam is sampled on a daily basis during the outmigration. The proportion of wild smolts for each year is determined from the sampling program. Estimates of the total hatchery fish released above Rock Island dam are compiled and adjusted to estimated numbers migrating past Rock Island Dam by applying an assumed smolt survival rate of .85 per project.

The method results in an annual estimate of natural smolt outmigration. Two major factors need to be considered in using the smolt outmigration estimates and brood year spawner counts to calculate smolts/spawner estimates. First, the annual migration is composed of smolts produced by several brood year spawnings. For any given brood year, the majority of outmigrants leave at either age 2 or age 3. Annual smolt age composition estimates are not available across the series. For the purposes of this analysis, the smolt outmigration in a given year was allocated equally to the brood year spawnings 2 and 3 years previous. The second major consideration is relative hatchery effectiveness. Given the high proportion of hatchery fish in the estimated escapement past fisheries in the upper Columbia region, the estimated number of smolts produced per spawner is a function of the assumed effectiveness of hatchery spawners. In general, the higher the relative effectiveness of hatchery spawners has been, the larger the adult spawning population that produced each years natural returns has been. The annual estimates of natural returns are independent of the assumption regarding hatchery effectiveness.

Table 7: *Calculation of the estimated smolt numbers passing Rock Island Dam (RIS) each migration year from 1985-98. Method from Peven & Hayes (1989). The total number of smolts passing RIS is estimated by dividing the estimated number of hatchery smolts passing RIS by the estimated percent of the smolt run that is of hatchery origin (smolt sampling program). Annual hatchery smolt releases are weighted by a factor reflecting the number of projects passed before RIS and average dam.*

Migration Year	Above Wells	Entiat & Wells H.	Wenachee	Estimated Hatchery Smolts @ RIS	% Hatchery at RIS	Estimated TOTAL RIS Smolt Run	Estimated NATURAL RIS Smolt Run
1985	416,552	75,105	248,420	613,218	17.6%	744,197	130,979
1986	443,733	248,760	174,120	174,120	27.5%	974,018	974,018
1987	578,809	46,520	332,970	790,702	18.9%	974,971	184,270
1988	826,208	43,960	319,700	954,001	17.4%	1,154,965	200,964
1989	651,853	38,350	304,945	808,506	17.8%	983,584	175,078
1990	740,433	36,915	297,300	863,641	20.9%	1,091,834	228,193
1991	657,007	47,360	477,063	992,007	15.8%	1,178,155	186,148
1992	514,610	47,270	484,230	896,215	28.8%	1,258,729	362,514
1993	511,025	41,480	391,558	796,032	37.8%	1,279,794	483,762
1994	359,112	43,210	480,375	776,562	32.1%	1,143,685	367,123
1995	359,112	43,210	480,375	776,562	26.7%	1,059,430	282,868
1996	359,112	43,210	480,375	776,562	13.2%	894,657	118,095
1997	359,112	43,210	480,375	776,562	12.2%	884,467	107,905
1998	359,112	43,210	480,375	776,562	29.2%	1,096,839	320,277
Weights:	0.7225	0.85	1				

Calculation of the estimated smolts per spawner for each brood year is based on a relatively simple equation:

$$Sm / Sp_{(yr)} = Sm_{(yr)} / (Spw_{(yr)} + Heff * Sph_{(yr)})$$

Where Sm = the smolt production estimate in migration year (I), Spw(yr) = the estimate of wild spawners contributing to the smolt production in year(I), Sph(yr) = the number of hatchery spawners escaping to spawning area, and Heff = effectiveness of a hatchery spawner relative to a spawner of natural parentage.

Smolt per spawner estimates are therefore a simple function of the estimated natural smolt production from a given brood year and the effective number of adult spawners. Average smolt/spawner estimates were calculated from the historical data series as a function of assumed relative effectiveness. Before the calculation, the annual estimated hatchery returns were reduced reflecting the assumption that any natural production from spawners in the Okanogan basin does not contribute proportionally to the total outmigration. The average smolts per spawner estimates corresponding to 25%, 50%, 75% and 100% hatchery origin spawner effectiveness are 158, 119, 95 and 90 smolts/spawner respectively.

Smolt to Adult Return Rates

The pattern in return rates for upper Columbia stocks is similar to a general pattern apparent in data sets representing many of the Columbia Basin/Oregon coastal summer steelhead runs. Chilcote (1997) summarizes stock return data for a number of Oregon steelhead stocks. Simple stock recruit functions are also included. An estimate of year to year environmental variations in return rates can be generated by comparing the patterns in residuals from the fitted stock recruit functions. Figure 10 depicts observed/expected returns by brood year for several summer steelhead stocks (data from Chilcote, 1997). Seven out of eight data sets examined exhibited similar patterns. The exception was the Kalama summer run. The peak in survival for the early 1980 broods was not apparent in the Kalama data. This may be explained by the immediate effects of the Mount St. Helens eruption in 1980 on the drainage (Dan Rawding, WDFW - Personal communication). Figure (11) illustrates the similarity in patterns between the average annual deviations in return rate from the Oregon summer steelhead stocks and the variations in upper Columbia steelhead.

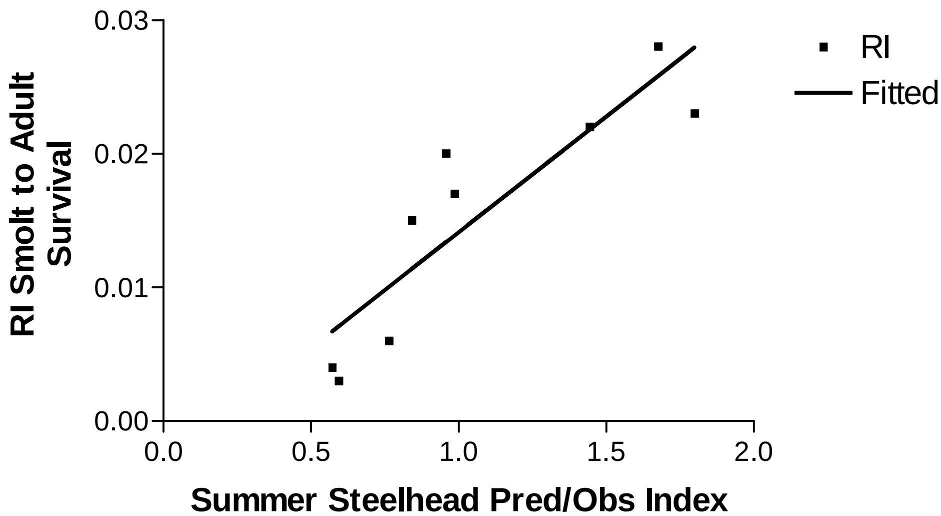

Figure 11 *Relationship between annual smolt to adult survival estimates for upper Columbia wild steelhead (based on Rock Island Dam estimates of smolts and adults) and an index of annual survival for other summer steelhead runs. (R-squared of .8030)*

The three lowest points on the graph correspond to the most recent three brood years in the data set

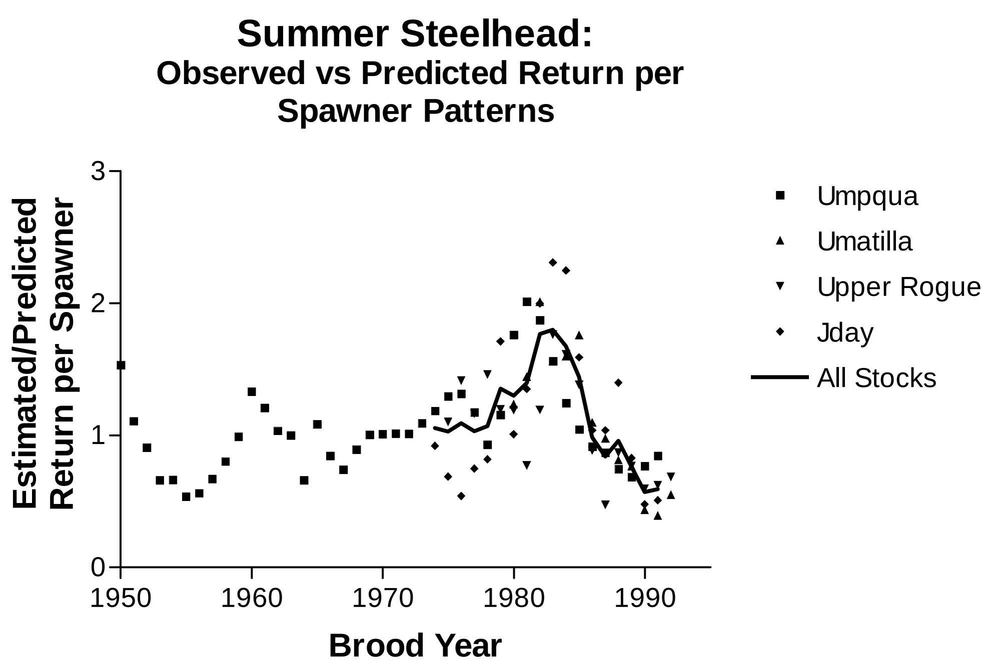

Figure 10 *Observed vs predicted return per spawner ratios. Early data from Umpqua sampling program for various summer steelhead stocks*

(1992,1993 and 1994). Although it is not possible to statistically differentiate these points, the pattern is consistent with an assumption that Upper Columbia steelhead stocks have been impacted to a higher degree than other summer steelhead stocks by poor environmental conditions.

A major uncertainty in quantifying smolt production potential under the habitat capacity approach is parr to smolt (overwintering) survival. Uncertainties are compounded due to the fact that unknown portions of annual parr production emigrate and may spawn downstream of weirs used in smolt counting. Estimates of overwintering survival are difficult to generate. It is generally believed that overwintering survival for upper Columbia spring chinook is on the order of 40% (Larry Brown, WDFW - pers. comm.). Applying the estimates of fecundity, egg to parr survival and egg to smolt survival described above results in estimated smolt carrying capacities at the top end of the ranges identified in the draft Biological Characteristics report.

3 Population Risk Assessment

The main purpose of the QAR exercise has been the development of baseline information and analytical tools for evaluating the future status of upper Columbia listed spring chinook and steelhead populations under alternative management actions. A major element of those analyses will be an assessment of the relative risk of extinction under alternative scenarios. Risk of extinction has been quantified in several different way for other Pacific salmon stocks (e.g., the CRI for Snake River examples, Botsford & Brittinacher (1998) for California Winter Chinook, for Rogue River summer chinook). In addition, the PATH process has largely incorporated quantitative life history modeling of Snake River chinook populations, with alternative actions being judged against return level criteria set up, in a sense, as surrogates for extinction risk (e.g., Marmorek, et al., 1998).

3.1 Approach

A Cohort Replacement Rate (CRR) model was used to generate estimates of extinction risks and the necessary changes in survival rate to meet alternative risk criteria. The following section briefly summarizes the rationale and the methods used to implement the approach. The CRR model can be used to project the relative risk of going below a particular quasi-extinction level given a continuation of recent spawner/recruit patterns. The basic modeling approach was adapted to information for each species in each tributary or tributary grouping. Age 3 returns (predominately males) were excluded from the analysis for the simple extinction risk assessments described below to ensure that the analyses reflected potential egg production. The cohort reconstruction model was amended to include the option of setting a carrying capacity on system smolt production.

Two sets of model runs were generated for each population. The first set evaluated performance under baseline conditions. The baseline for hydropower impacts was the 1982 (1980 brood year) through 1996 configuration and operations. All of the major mainstem dams directly affecting migrating upper Columbia salmon populations were in place prior to this period. The baseline for harvest management was generally the most recent 5 year average available (e.g., 1991-95 seasons). Harvest impacts on steelhead changed dramatically in the mid-1980's with the imposition of wild steelhead non-retention in mainstem and tributary sport fisheries. Returns to the spawning grounds were adjusted to reflect recent year average harvest rates. As a result, modeled escapements for the baseline series were projected to be significantly higher than those actually observed for return years prior to 1985. The set of model runs incorporating these baseline assumptions were run to generate estimates of extinction risk at 24, 48, 75 and 100 years. In addition, an estimate of the median average population growth rate was calculated for each population under baseline conditions. A second set of model runs were compiled to estimate the relative change in survival required to reduce extinction risks to below 5% at 24, 48 and 100 years and to estimate the required survival change necessary to meet draft recovery objectives in 48 or 100 years.

An expanded version of the CRR model was developed to evaluate assumptions regarding ongoing supplementation strategies for both spring chinook and steelhead populations representing the upper Columbia. This approach directly incorporated age specific sex ratios and fecundates. The simple life cycle model incorporates survival estimates through particular life stages. This format makes it relatively easy to model the end effect of actions that are projected to change the survival in a major life history stanza (e.g., egg to smolt survival, smolt to adult survival, adult upstream passage/fishery survivals). The tradeoff for the ability to directly incorporate life stage survival changes and carrying capacity is the increase in model complexity - additional parameters need to be estimated and incorporated into the life history model.

An alternative extinction risk assessment approach designed for use when minimal data are available to describe population histories has been developed and applied to Columbia River listed runs (McClure et al., 2000). That approach is based on variations on the simple extinction model described in Dennis et al (1991). The model was intended to be fit to a series of population counts over time. The model includes the effect of both the average growth rate and 'drift' from the average resulting from year to year variations. The model includes a specific analytical approach that allows estimating the risks of going below a future threshold (usually set at 1 individual) as well as a set of confidence limits about the average risk. The Dennis model has been applied to a number of terrestrial species (e.g., Dennis et al, 1991, Morris et al, 1998). Holmes (2000) describes a method for developing estimates of annual population growth rate and it's standard deviation. That approach is based on accumulating running sums of the number of present and future spawners that are alive in a given year. The ratio of the sums for adjacent years is used as a basis for calculating lambda. The results of applying the Running Sums analysis to the Upper Columbia runs has been summarized in McClure, et al., (2000a & b).. A comparison of the results using the CRR model and the output from applying the running sums is included below.

3.2 Criteria

The models described above can be used to generate projections of temporal trends or patterns in spawning escapement that can be compared against specific extinction risk criteria. The draft QAR Population Structure and Biological Requirements Report characterizes three types of low population size criteria for consideration.

Absolute Extinction Level is defined as one or fewer spawners in five or more consecutive years. Given the age structure of spring chinook salmon runs in the upper Columbia, this criteria is the equivalent to complete extinction of the subject population.

Quasi-Extinction Criteria: Defined as 50 or fewer spawners (Methow or Wenatchee) or 30 or fewer spawners (Entiat) for five or more consecutive years. The draft report provides the biological meaning of this level - "Abundance level at which a population is believed to be 1) at extremely high risk of extinction in the immediate future, and 2) faces risks that are not usually incorporated into simple population extinction models."

The draft report also recommends consideration of a third level for spring chinook runs - a Cautionary Level equal to 1200 or fewer spawners per year for the Wenatchee, 750 for the Methow, and 150 for the Entiat.

Analyses in support of the 2000 FCRPS Biological Opinion used a set of risk criteria including a modeling equivalent to absolute extinction. A similar criteria was applied to the CRR model results. The CRR model operates on an annual time step. The proportion of runs resulting in a return of 0 adults in a given year was reported as a basic measure of extinction risk. In addition, both models were used to assess the probability of the modeled populations falling to 90% of their respective current levels within 24, 48 or 100 years.

Recovery Criteria: The draft Biological Requirements Report identified interim population recovery goals for the three existing upper Columbia Spring chinook populations; 3,750 spawners/year in the Wenatchee, 2,000 spawners/year in the Methow River, and 500 spawners/year for the Entiat River (Table 3.1. in Ford, et al., 2001). The results of several different methods of estimating carrying capacity were considered in the selection of these values. One set of approaches involved generating estimates of smolt carrying capacity by applying maximum parr production estimates per unit habitat to estimates of the available habitat in each of the upper Columbia River systems. Maximum parr production estimates per 100m2 from studies in other tributaries were used.

The Biological Requirements Report recommends Interim Recovery Level (IRLs) of for the Wenatchee, Methow and Entiat steelhead runs. The recommended IRL's for the Wenatchee and Methow are 2,500 spawners. The level for the Entiat was recommended at 500 spawners, consistent with the relative habitat capacity of that system.

3.3 Cohort Replacement Rate Model (CRR)

Botsford & Brittinacher (1998) developed extinction risk assessments for the listed Sacramento River winter chinook salmon population. They noted that the Dennis model approach, when applied to spawning escapements, does not account for the particular life history patterns common to many northwest salmon and steelhead runs - the occurrence of multiple ages at adult return (fig. 10) from a given years spawning production and the fact that all, or a very high proportion of, adults die after spawning. Botsford and Brittinacher (1998) suggested an approach to estimating extinction risks that directly incorporates multiple contributions from different brood years to any given years production (fig. 12). The general approach involves calculation of a cohort replacement rate from historical data, and then projections using that rate and it's variance into the future. The method Botsford and Brittinacher (1998) used to carry this out was tailored to the Sacramento Winter chinook situation. In particular, it was set up to use an average proportion returning by age in fitting a series of annual survival rates given the adult spawner counts and a

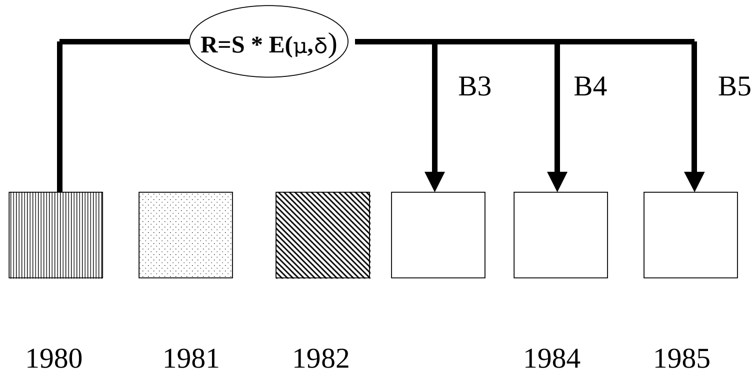

Figure 12 *Schematic representation of production from one brood year spawning escapement distributed over three future return years.*

fixed age at return structure. The CRR model used in this analysis takes the form:

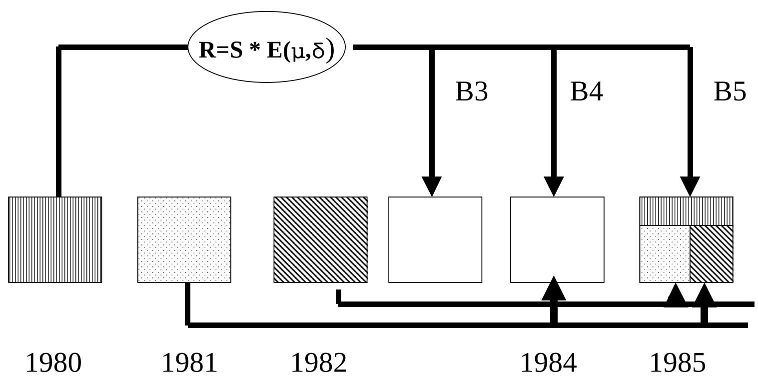

Figure 13 *Schematic representation - multiple brood years contributing to each future brood year return.*

$$S_{(t)} = \sum_{i}^{3-5} S_{(t-i)} * \sigma_{(i,t-i)} * E_{(t-i)}$$

$S_{(t)}$ is the estimated adult spawning escapement in year t. . S(t-I) is the number of spawners I years previously. Sigma(i,t-I) is a factor reflecting the relative productivity (fecundity, proportion female) of spawners in year (t-I) that are of age I. It is also a function of the brood year specific maturity rates in the data series. In the analyses described below, it is simply the average brood year specific proportion of returns by age. E(t) is a year specific survival factor determined empirically from the historical data series. In this analysis, E(t) was estimated by comparing brood year production to the spawning grounds against brood year spawning. The time series of brood year production estimates were developed by adding up brood year components derived by applying annual age composition estimates to estimated adult returns by return year This term is assumed to be lognormally distributed. It captures the annual variation in survival as well as estimation error inherent in each brood year series subject to analysis. The lognormal distribution is commonly applied to such terms in salmon population analyses (e.g., Hilborn & Walters, 1992).

Monte Carlo simulation approach was used to generate quasi-extinction risk estimates. The model described above was set up in an excel spreadsheet. Spawning escapements for the initial years in the model were set at recent average levels. The model operates on an annual time step, generating future spawning escapements as a simple function of the current year escapement, average age distribution and a random year specific factor drawn from a distribution matching a particular time period (e.g., 1960-94, 1970-94 or 1980-94 for upper Columbia spring chinook, 1976-94 for upper Columbia steelhead) for the stock being modeled. After the initial years, each annual time step in the model included three sets of calculations:

1. Spawning escapement in the year was calculated based on previous years Production estimates and average brood year age composition. The spawning escapement is compared against the particular QUASI-EXTINCTION threshold selected for the run. Most of the runs described below used a threshold of 2 adult spawners. If the estimated escapement is LESS THAN the threshold, subsequent RECRUITMENT was set to 0.

2. A year specific random factor is drawn from a natural lognormal distribution (e.g., Figure 14) based on a selected time period for the stock under analysis. Three time periods were used in the analyses. A recent time period corresponding to the years used in CRI Snake River analyses 1980-94 brood years - corresponding to base period for CRI Snake River analyses, 1970-93 brood years - corresponding to years of relatively consistent harvest impacts and age/spawning count availability , and 1960-94 - extended time series including higher survival years in the 1960's.

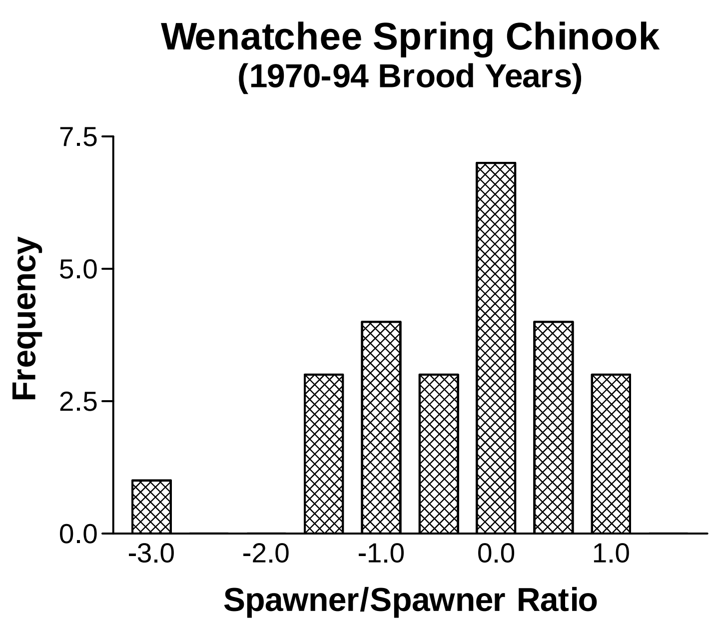

Figure 14 *Frequency distribution of Wenatchee spring chinook spawner to spawner ratios (1970-94 brood years) Natural lns of r/s data in Table (2).*

3. Brood year production of adults FROM the current escapement is calculated by multiplying the current adult spawning escapement (ages 4+) by the factor (Fig. 14).

That cycle is repeated for the duration of a run - usually out 150 to 200 model years. Figure 15 illustrates individual runs from a base run using Wenatchee spawner/return data set.

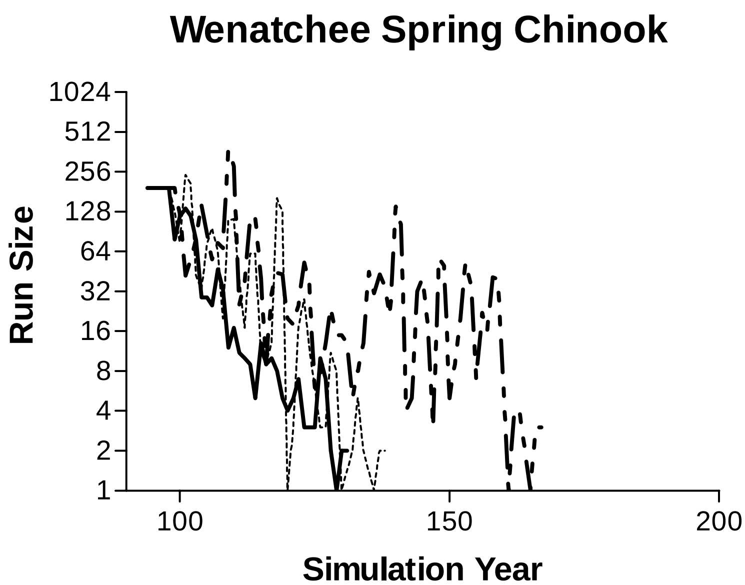

Figure 15 *Projected escapements for three Monte Carlo simulation runs of the cohort reconstruction model using the natural ln mean and standard deviation derived from the Wenatchee Spring Chinook spawner/spawner data set (1980-94 brood years).*

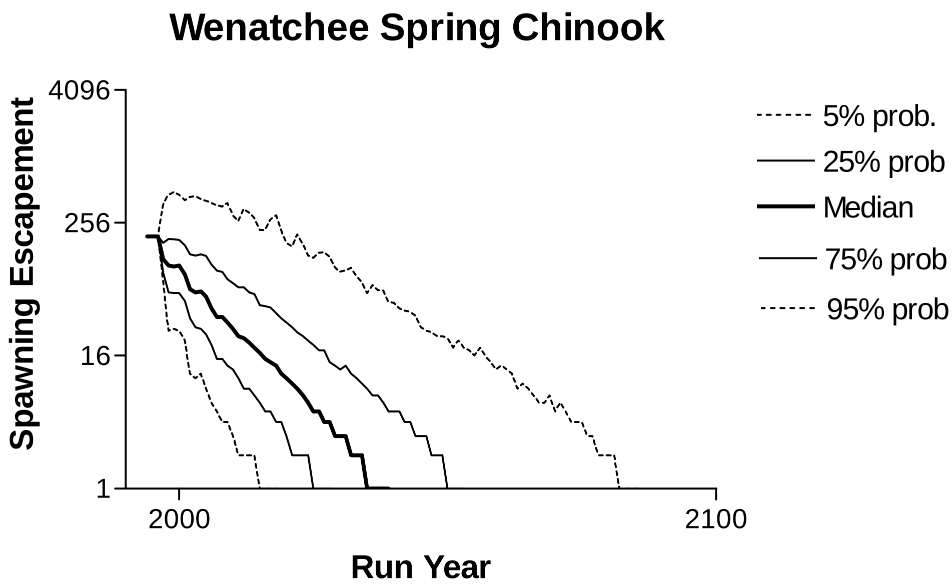

Figure 17 *Example of cumulative statistics over 1,000 simulations using Wenatchee 1980-94 Sp/Sp data in Cohort Replacement Rate model. Note ln(base 2) scale on y axis.*

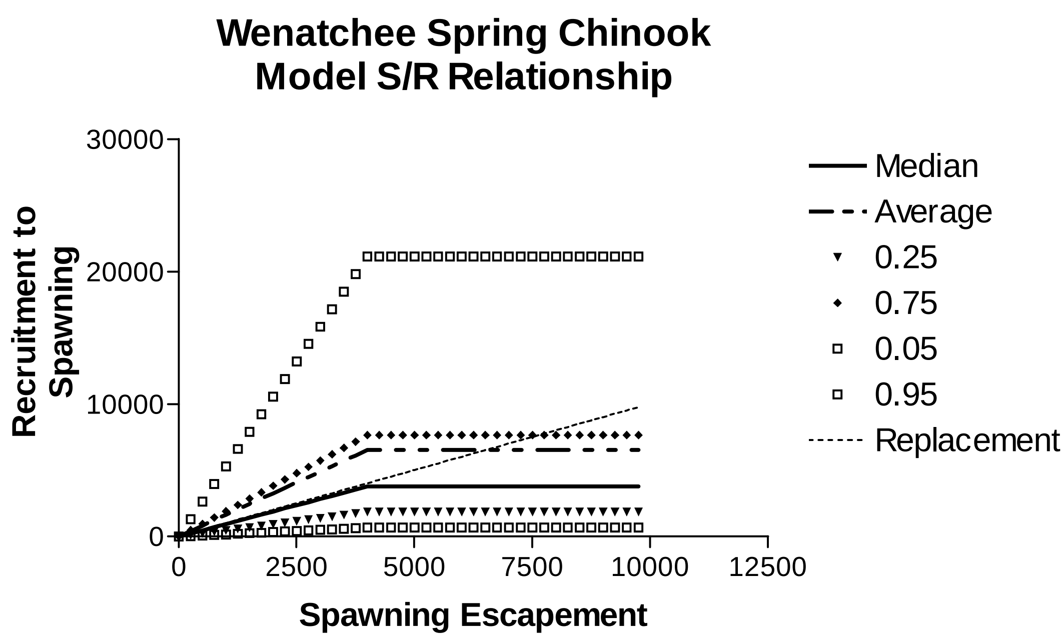

Figure 16 *Example of spawner-recruit relationship generated by model. Lines denote median and average returns, symbols illustrate confidence bounds.*

For a given scenario, the 150 -200 year model run is repeated 1,000 times to compile a data set for use in generating summary statistics (fig. 17). The results are saved to a separate spreadsheet and a post-processing routine is used to compile summary statistics. Model results can also be summarized in terms of brood year production. Figure 16 illustrates the range in production generated by the model given particular input values for the lognormal mean, standard deviation and ceiling.

Assumption Analyses

The risk assessment model was run under a range of alternative assumptions regarding future climate/environmental assumptions (represented by different ranges of historical years). In addition, risk assessments were run under two different scenarios regarding supplementation. Spring chinook and steelhead natural supplementation efforts are well underway in the upper Columbia basins.

The model was also designed to capture simple time series correlation in the historic data series using the following algorithm:.

Step 1: For each series, the spawner to spawner return rate in year I+1 was paired with the estimate for year I. The resulting pairs were divided into two series for each stock, pairs in which the first pair element was positive (ln spawner to spawner greater than 0), and a series in which the first value was negative (ln spawner to spawner less than 0). The proportion of times the second value in the series had the same sign as the first value was recorded.

> P(pos) = proportion of the paired data series where a positive ln(s/s) ratio was followed by another positive ratio.
>
> P(neg) = proportion of the paired data series where a negative ln(s/s ratio was followed by another negative ratio.

Step 2: Each series of ln (spawner/spawner) ratios was grouped into positive and negative values and the mean and standard deviation of those subgroups were taken.

> Avg(pos) = average ln(spawner/spawner) of the values greater than 0 in the data series
> Stnd(pos)= standard deviation of the ln(spawner/spawner) values greater than 0
>
> Avg(neg) =average ln(spawner/spawner) of the values less than 0 in the data series
> Stnd(neg)= standard deviation of the ln(spawner/spawner) values less than 0

The approach was implemented into the simple Cohort Return Rate model at each year step following the initial year in the model run. The method uses the initial draw from the overall distribution of ln(spawner/spawner) for the series for year 1. The draw for each subsequent year is determined by the following algorithm.

Step 1. generate a random number between 0 and 1 (Rand(a)).

Step 2. If Ln(S/S) for year n-1 is positive

If Rand(a) < P(pos) then draw S(n) from positive distribution (Avg(pos), Stnd(pos).

If Rand(a) >P(pos) then draw S(n) from negative distribution (Avg(neg), Stnd(neg).

If Ln(S/S) for year n-1 is negative

If Rand(a) < P(neg) then draw S(n) from negative distribution (Avg(pos), Stnd(pos).

If Rand(a) >P(neg) then draw S(n) from positive distribution (Avg(neg), Stnd(neg).

Average spawner to spawner survival in this simple model encompasses survival across all life stages - egg to smolt, smolt to adult, adult to spawner. Proportional survival changes at the spawner to spawner level would be calculated by multiplying the proportional change at each life stage together.

Survival(ss) = S(e,p) * S(p,s) * S(s,a) * S(a,sp)

Where S(ss) = geometric mean spawner to spawner survival rate

S(e,p) =geometric mean egg to smolt survival rate
S(p,s) = geometric mean parr to smolt survival rate

S(s,a) = geometric mean smolt to adult survival rate

S(a,sp) = geometric mean adult to spawner survival rate

Each of these terms can be further subdivided as data permits. The following section on Leslie matrix modeling uses a particular set of life stage breakdowns adapted to the information available for upper Columbia runs.

The risk assessment analyses described below focus on the following questions:

How much improvement in productivity (population growth rate) would be required to meet alternative spawning escapement criteria in the absence of supplementation?, and;

How much improvement in productivity (population growth rate) would be necessary to maintain the populations at their Interim Recovery objectives if supplementation were to be discontinued once the delisting levels were reached?

3.3.1 Key Assumptions

Simple models designed to explore extinction risks like the Cohort Replacement Rate model and the Dennis model are based on a well known set of simplifying assumptions (e.g., Morris et al, 1999).

> The population counts used in constructing the annual spawning estimates are assumed to represent a consistent proportion of the population of interest.
>
> Year to year variations in the counts reflects random environmental influences, and the data is assumed to have been gathered over a long enough period to reflect longer term average conditions.
>
> A related assumption is that the variation can be described using standard statistical methods, in this case, that means that the year to year variation in returns per spawner can be described by a lognormal distribution.
>
> A fourth major assumption is that the data series is not influenced by density dependence - the annual population growth rate is assumed to be independent of population size.

It is difficult to demonstrate density dependence in short time series of salmon spawner-recruit data, much less to accurately describe the quantitative relationships involved. In extinction risk assessments, attention has focused on the effects of incorporating or not incorporating density dependence at low run sizes (e.g., Ginzburg, et al, 1990). In most cases assuming productivity rates independent of run size at low population levels results in more conservative (pessimistic) results than assuming density dependence. Models incorporating depensation could be an exception.

Finally, application of the Dennis et al (1991) modeling approach assumes that productivity rates derived from brood year return per spawner estimates can be approximated with a simple linear diffusion equation. This approach does not directly incorporate the contributions of multiple brood years to each spawning escapement, although the age structure of the population is used in calculating average generation time.

The CRR approach incorporates both the age at return structure and the multiple brood contributions to sequential run years characteristic of Pacific salmon populations. The rates used are derived from upper Columbia spring chinook population data sets described above. In addition, the CRR simulation model was easily adapted to include an upper ‘limit’ on production corresponding to independent estimates of carrying capacity. Carrying capacity was not an issue for historical assessments of productivity or for forward projections under historical conditions. However, projections assuming improved survival can reach levels well above historical escapements, with the extremes building to levels that are clearly outside the capacity of the systems.

The CRR model developed for this effort can produce estimates of average annual growth rate for direct comparison to results derived using the running sum based approach described in Holmes (2000).

3.4 Spring Chinook Risk Assessment

Preliminary attempts to apply this approach to the Wenatchee Spring chinook data indicated a problem with fitting an age composition vector to the data series of escapements. The best fit estimates derived using the Excel spreadsheet routine Solver tended to reduce some brood year survivals to zero or to negative values, while estimating adjacent years at very high levels. Botsford & Brittinacher (1998) reported a similar problem with Sacramento Winter Chinook data sets. Independent estimates of annual age composition are available for the upper Columbia spring chinook runs, at least for adult returns going back to the late 1950's. Brood year based spawner to spawner estimates (transformed into natural ln's) were used in to estimate tributary specific sets of E(t) values for upper Columbia Spring chinook.

Analysis of the data series of Return/spawner estimates indicated a high likelihood of consecutive runs of relatively high or low values - that is, if survival in year(I) was low, it was more likely that survival in year(I+1) would also be low. High survival years were also more likely to be followed by high survivals the subsequent year. A set of runs were made to mimic that pattern using a simple correlation model (Rick Deriso, personal communication). Input parameters for that variation were derived from the tributary data series through a simple procedure. A sequential list of annual return per spawner estimates was prepared. A second column was added pairing the estimate in year (I+1) with the estimate in year (I). The data set was then divided into two subsets - pairs in which the first column value is greater than 0 (positive - R/S greater than 1) and pairs in which the first value was below 0. For each subset, the proportion of occurrences of positive and negative values in the second year was determined. The mean and standard deviation of each major set was also determined. That information was used with a random number generator to mimic the year to year correlation in the data set.

The following tables summarize model results from two different basic scenarios. The first set of model runs used recent return levels as a starting point for the extinction risk assessments, the second set of runs were conducted using the Interim Delisting Level as initial population levels. The first set of runs are intended to reflect extinction risks given recent historical survival rates and no benefits of supplementation with hatchery production. The sensitivity analyses described above were run under this scenario. The second scenario assumes that the population is elevated to the level of its Interim Delisting Objective through a short series of high survival years or through artificial production - but that long term return rates remain at recent historic levels. This is a simplistic representation of a scenario where hatchery supplementation is used to quickly achieve population abundance objectives in the absence of a change in survival. NMFS has recognized that there is a potential role for carefully designed and monitored supplementation in recovery efforts , but that in the longer term the ultimate goal of a recovery plan must be to achieve both abundance goals and the conditions necessary for natural production to be self-sustaining.

In 1993, the NMFS entered an interim policy regarding artificial production into the Federal Register (Vol. 58(63):17573-17576). That policy recognized that “(t)he goal of the Endangered Species Act is the conservation of species in the context of their natural environment.”

> The stated purposes of the ESA are to provide a means whereby the ecosystems upon which endangered species depend may be conserved, to provide a program for the conservation of such endangered species and threatened species, and to take such steps as may be appropriate to achieve (these) purposes {ESA sec 2(b)}.

In the case of Pacific salmon, that goal translates into providing sufficient improvements so that an appropriate set of populations within a listed ESU could be self-sustaining in their natural environment. Ultimately, a recovery program should demonstrate that:

> *"A viable salmonid population that includes naturally spawning hatchery fish should exhibit sufficient productivity from naturally produced spawners to maintain population abundance at or above viability thresholds in the absence of a hatchery subsidy.* " (from McElhany, et al., 2000 page 17).

NMFS has recognized that artificial production could play an important role in the rebuilding phase of a natural stock. (e.g., Hard, et al., 1992) for example, as a means of reducing extinction risk during the time necessary to address key survival factors. The long-term use of supplementation as a mitigation tool may also be possible, as long as it can be demonstrated that 1) conditions have been meet as necessary for the natural population to be self-sustaining in the absence of supplementation, and 2) there are no significant long-term negative effects of the ongoing supplementation program on the natural stock..

Table 8: *Runs initiated with spring chinook spawning escapements AT RECENT AVERAGE LEVELS. Quasi-extinction criteria used was Quasi-extinction criteria used was the proportion of runs with 0 returns to spawning ground at 10, 24, 48 and 100 years.*

Stock	Period	*Population Statistics*		*Cumulative Extinction Risk at*:		
		Geometric Mean R/S (+/- 1 s.d.)	***Lambda (Model Generated)***	***24 Years***	***48 Years***	***100 Years***
Wenatchee Spring Chinook	***1980-94+***	***.42 (.14 - 1.32)***	***0.88***	.15	.57	.98
	1970-94+	***.57 (.21 - 1.53)***	***0.94***	.01	.19	.73
	1960-94+	***.79 (.28 - 2.24)***	***1.03***	--	.003	.02
Methow Spring Chinook	***1980-94+***	***.55 (.15 - 2.00)***	***0.94***	.01	.15	.50
	1970-94+	***.57 (.19 - 1.71)***	***0.95***	.02	.24	.72
	1960-94+	***.75 (.25 - 2.24)***	***1.03***	.00	.00	.05
Entiat Spring Chinook	***1980-94+***	***.41 (.19 - .88)***	***0.89***	.16	.83	.99
	1970-94+	***.59 (.25 - 1.44)***	***0.98***	.02	.10	.47
	1960-94+	***.81 (.29 - 2.28)***	***1.03***	.00	.00	.003

Risk of extinction is projected to be high under each of the scenarios analyzed (Table 8). Short-term extinction risks for the upper Columbia spring chinook were relatively low under all scenarios except for the runs made under the assumption that long-term survivals would be similar to those observed from 1980-94. The Wenatchee and Entiat model runs had the highest short term risk at roughly 15%. Wenatchee and Entiat model runs indicated relatively high risks of extinction over 48 years for the 1980-94 simulations and moderately high for the 1970-94 scenarios.. Extinction risks are projected at very high levels for the scenarios based on 1980-94 and the 1970-84 brood year return/spawner rates. Extending the series to include brood year return/spawner estimates from the 1960's resulted in substantially reductions in the projected extinction risks.

Adding in year-to-year correlation mimicking the relationships within the respective data series did not change the projected extinction risk significantly. The models project it would take 5 to 10 generations for 50% or more of the runs to go to extinction. The level of year to year correlation in the historical data series is not sufficient to increase the variance around the downward trend in survival over that many generations.

A detailed analysis of supplementation options for the Upper Columbia is outside the scope of this analysis. However, a simple analysis was conducted to illustrate the potential effect of a short-term supplementation program on the survival changes required to meet survival and recovery criteria.

A set of model runs (Table 9) were made under the assumption that supplementation could successfully boost return levels up to the proposed Interim Recovery goals (Draft QAR Biological Requirements Report). The set of runs assumed that supplementation would then be turned off. Short term extinction risks as represented by projections at 10 and 25 years would be reduced under this scenario. But long term (75 year and 100 year) extinction risks were almost equal to the projected risks in the absence of supplementation. Supplementation may be able to sustain production under adverse survival conditions at least for a period of time. However, improvements in survival would be necessary to allow for sustainable natural production in the absence of hatchery intervention.

Table 9: *CRR Model Runs initiated with spawning escapements AT INTERIM RECOMMENDED DELISTING LEVELS. Quasi-extinction criteria used was the proportion of runs with 0 returns to spawning ground at 10, 50 and 100 years.*

Stock	**Period**	***Geometric Mean R/S*** (+/- 1 .s.d)	***Cumulative Extinction Risk***		
			10 Years	***50 Years***	***100 Years***
Wenatchee Spring Chinook	***1980-94+***	***.42 (.14 - 1.32)***	.000	.69	.98
	1970-94+	***.57 (.21 - 1.53)***	.000	.32	.87
	1960-94+	***.79 (.28 - 2.24)***	.000	.11	.54
Methow Spring Chinook	***1980-94+***	***.55 (.15 - 2.00)***	.001	.02	.21
	1970-94+	***.57 (.19 - 1.71)***	.000	.000	.01
	1960-94+	***.75 (.25 - 2.24)***	.000	.000	.01
Entiat Spring Chinook	***1980-94+***	***.41 (.19 - .88)***	.002	.22	.96
	1970-94+	***.59 (.25 - 1.44)***	.000	.001	.08
	1960-94+	***.81 (.29 - 2.28)***	.000	.000	.000

Substantial improvements in average survival would be required to avoid relatively high quasi-extinction risks under the scenarios in which starting population levels were set at delisting target levels. The models respond to the cumulative effect of survivals across life stages. The necessary change in survival to meet the standard could come from improvements in a single life stage (e.g., egg to parr survival), or the improvements could be a composite of survival gains in more than one life stage.

3.5 Steelhead Risk Assessment

The steelhead run-reconstruction data set described above was used to generate a historical series of brood year return per spawner for two population composites: steelhead runs above Wells (dominated by production from the Methow basin) and the combined runs into the Wenatchee and Entiat River systems. The lack of tributary specific escapement estimates restricted the run reconstruction to these regional aggregates. Run reconstructions for upper Columbia River steelhead components were extended back to run year 1976. For this analysis, brood year return rates were expressed in terms of adult fish to the spawning grounds. Spawning escapements for each brood year were the composite estimate of hatchery and wild returns to the spawning grounds. Composite harvest rates (tribal and non-tribal fisheries) prior to 1985 were substantially higher than recent annual rates. Spawning escapement estimates for those years were adjusted to recent year rates to allow calculation of average return rates under recent year harvest assumptions. The adjustment was made by multiplying return rates prior to 1985 by the proportional change in escapement rate (1minus the harvest rate). Adult returns for each brood year were reconstructed by applying return year age composition estimates (Priests Rapids Dam sampling Program) and allocating the resulting components to the corresponding brood year. Earlier years in the series were subjected to significantly higher harvest rates prior to 1985. Returns prior to 1985 were adjusted on a calendar year basis to reflect more recent harvest rates.

In recent years escapements of adult steelhead into the upper Columbia have included substantial numbers of returning hatchery fish. The degree to which these returning hatchery fish are contributing to spawning and to subsequent juvenile production is not clearly understood. The relative effectiveness of hatchery spawners relative to their natural counterparts could be determined by at least three factors; differences in relative distribution of returning hatchery adults relative to natural steelhead, differences in spawning timing, and differences in the fitness of offspring. The distribution of returning hatchery fish relative to natural production areas is not directly known for the upper Columbia. Conditions at the time of spawning make direct surveys difficult in the upper reaches of these tributaries. Most steelhead hatchery releases have been made in tributary mainstems. The extent to which fish released in the mainstems migrate upriver to spawning areas used by spawners of natural origin is not known. Hatchery returns to the Mid-Columbia are submitted to management regimes within the facilities designed to accelerate spawning and rearing in order to produce large, high quality smolts for release the subsequent year. Spawning timing in the hatchery is typically 2-3 months earlier than wild spawning. The degree to which this long-standing practice has been selective is not known. If returning hatchery fish have a strong propensity to spawn early, that may limit areas in the basins accessible to naturally spawning hatchery returns. In many years, upper tributaries are inaccessable because of ice and flow conditions at the time of hatchery spawning. A secondary effect of early spawning may be increased susceptibility to redd scour under freshet conditions. The third factor, genetic fitness of first generation progeny, is also not clearly understood for upper Columbia runs. Hatchery runs have similar river entry timing to wild runs and broodstock are taken from returning fish.

The steelhead run reconstruction results were used to develop two model populations, one representing spawners above Wells Dam, the other a composite of the Entiat and Wenatchee populations. General production characteristics developed through the historical analysis described above were applied to both populations. Natural production ceilings were established at the carrying capacity estimates described above. Natural production from the above Wells region was assumed to originate from the Methow basin. The estimated number of hatchery spawners above Wells was discounted by 1/3 to represent returns into the Okanogan basin, consistent with the ratio of smolt plants into the two areas in recent (post 1975) years.

Assumptions regarding the relative effectiveness of hatchery spawners will have a significant influence on the population parameters derived from recent spawner-recruit data series (Table 10). Natural stock productivity was evaluated under four alternative assumptions regarding hatchery effectiveness 1) hatchery spawners equally effective as natural spawners; 2) hatchery spawners 75% as effective; 3) hatchery spawners 50% as effective; and 4) hatchery spawners 25% as effective as their natural counterparts.

It is possible to calculate an estimate of the return level necessary to produce full seeding given estimates of habitat capacity and an estimate of the smolt production per spawner at relatively low run sizes. General analyses of smolts produced per spawner for the aggregate upper Columbia run indicate an average production rate of 66 smolts/adult spawner (males and females combined) . Assuming that any differential between hatchery and wild spawners would be manifested in either spawning success or juvenile (parr) production rates, the smolt/spawner rate was adjusted upwards to reflect the alternative relative hatchery effectiveness assumptions described above.

Table 10: *Steelhead Extinction analysis results. Projection of extinction risks if current hatchery augmentation is immediately discontinued and recent (1976-92 Brood) survival conditions continue indefinitely. Model runs under three different assumptions regarding hatchery effectiveness (1.0, .75 and .50). Table entries = proportion of runs at year () meeting criteria*

Upper Columbia River Steelhead	**Historical Hatchery Effectiveness Assumption**	**Model Extinction Risk (0 spawners at year 25, 50, 75 or 100)**			
		Year 25	**Year 50**	**Year 75**	**Year 100**
Wenatchee/Entiat	1.0	.00	0.99	1.00	1.00
	.75	.00	0.80	1.00	1.00
	.50	.00	0.26	0.99	1.00
	.25	.00	.00	0.08	0.35
Methow	1.0	0.10	0.99	1.00	1.00
	.75	0.03	0.96	1.00	1.00
	.50	.00	0.60	0.97	0.99
	.25	.00	0.03	0.11	0.28

4 Necessary Survival Changes

4.1 Spring Chinook

The cohort reconstruction model was used to estimate the required survival change needed to meet quasi-extinction risk and recovery criteria, employing input factors derived for each of the three upper Columbia spring chinook population sets. Survival changes were expressed as simple proportional increases applied to the brood year spawner to spawner rates drawn randomly from the historical series. Theoretically, the required survival improvements identified in this analysis could be achieved by the composite effects of improvements in one or more life history stages. Analyzing the potential actions or programs is not necessary in this step of the analysis, although it is clear that identifying potential actions evaluating their feasibility are critical to a successful rebuilding effort.

4.1.1 CRR Model Results

For each stock, a series of runs were made with incrementally increasing survival improvements. Estimated survival increases corresponding to specific survival or recovery criteria were taken directly from the list or extrapolated from ‘bracketing’ values as appropriate. The simulation results using the Wenatchee Spring chinook data set are summarized in Table 11. Model results are responsive to starting population size and to the average and standard deviation of the annual spawner to spawner ratios. Two starting population sizes were used in the analysis 1) a recent five year average and 2) a rough estimate of biological carrying capacity.

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Table 11: *Wenatchee Spring Chinook - percentage change in survival projected as necessary to meet survival and recovery criteria under alternative base survival assumptions.*

Wenatchee Spring Chinook	**Baseline R/S Data Set**	**Survival Change (Generation) Need to Meet Criteria**					
		Risk of '0'Adult Spawners at 24 Years		**Risk of '0' Adult Spawners at 100 Years**		**Median Esc. Greater then Interim Recovery Level over 8 years**	
		<5%	**<1%**	**<5%**	**<1%**	**Year 41-48**	**Year 91-100**
From Recent Avg. Level (193)	1980+	***7%***	*32%*	***75%***	*90%*	***170%***	***155%***
	1970+	*0%*	*0%*	***35%***	*47%*	***110%***	***92%***
	1960+	*0%*	*0%*	*0%*	*5%*	***40%***	***15%***
From Interim Recovery Abundance (3,750)	1980+	*0%*	*0%*	***48%***	*72%*	***120%***	***115%***
	1970+	*0%*	*0%*	***17%***	*22%*	***95%***	***90%***
	1960+	*0%*	*0%*	*0%*	*0%*	***25%***	***20%***

The Wenatchee required the largest increases in cohort replacement rates (Geomean return/spawner) of the three spring chinook data sets. The largest increases correspond to the assumption that conditions since 1980 will continue on into the future. Assuming conditions will reflect the data series since brood year 1970 results in a decrease in the survival improvement necessary to meet various criteria. Cohort return rates during the 1960's were consistently higher than in the more recent periods, even after adjusting to recent harvest and direct dam impact rates. Survival improvements are needed to meet each of the criteria under the 1960+ scenario, although the increments required are substantially smaller.

Results for the Methow and Entiat Spring chinook runs are summarized in Tables 12 & 13. Each of these model run sets showed similar patterns in results to the Wenatchee.

All of these runs were carried out assuming that a simple 'broken stick' model of production was in effect. Under this assumption, production of recruits at adult escapements below the interim delisting levels were generated by multiplying adult escapement by a factor drawn from a lognormal distribution reflecting the chosen historical time series for the stock. If the parent escapement was above the draft delisting level for the stock, production for the subsequent generation was calculated by multiplying the randomly drawn factor against the delisting goal. In other words, if escapements exceeded the goal, the subsequent recruitment was calculated as if the escapement was equal to the goal.

Table 12: - *percentage change in survival projected as necessary to meet survival and recovery criteria under alternative base survival assumptions.*

Methow Spring Chinook	**Baseline R/S Data Set**	**Survival Change (Generation) Need to Meet Criteria**					
		Risk of '0'Adult Spawners at 24 Years		**Risk of '0' Adult Spawners at 100 Years**		**Median Esc. Greater then Interim Recovery Level over 8 years**	
		<5%	**<1%**	**<5%**	**<1%**	**Year 41-48**	**Year 91-100**
From Recent Avg. Level (175)	1980+	*0%*	*5%*	***32%***	*47%*	***105%***	***95%***
	1970+	*0%*	*0%*	***34%***	*48%*	***100%***	***95%***
	1960+	*0%*	*0%*	***19%***	*10%*	***52%***	***45%***
From Interim Recovery Abundance (2,000)	1980+	***0%***	*0%*	***16%***	*35%*	***55%***	***55%***
	1970+	***0%***	*0%*	***14%***	*26%*	***50%***	***50%***
	1960+	***0%***	*0%*	***0%***	*0%*	***15%***	***15%***

Table 13: *Entiat Spring chinook - percentage change in survival projected as necessary to meet survival and recovery criteria under alternative base survival assumptions.*

Entiat Spring Chinook	**Baseline R/S Data Set**	**Survival Change (Generation) Need to Meet Criteria**					
		Risk of '0'Adult Spawners at 24 Years		**Risk of '0' Adult Spawners at 100 Years**		**Median Esc. Greater then Interim Recovery Level over 8 years**	
		<5%	**<1%**	**<5%**	**<1%**	**Year 41-48**	**Year 91-100**
From Recent Avg. Level (45)	1980+	***12%***	*22%*	***57%***	*67%*	*112%*	***100%***
	1970+	***0%***	*0%*	***18%***	*23%*	*62%*	***52%***
	1960+	***0%***	*0%*	***0%***	*2%*	*22%*	***17%***
From Interim Recovery Abundance (500)	1980+	***0%***	*0%*	***38%***	*42%*	*100%*	***100%***
	1970+	***0%***	*0%*	***4%***	*8%*	*15%*	***20%***
	1960+	***0%***	*0%*	***0%***	*5%*	*15%*	***15%***

The estimated changes in survival necessary to meet quasi-extinction and recovery criteria were sensitive to the assumed ceiling or carrying capacity on adult production. As described above, the ceilings implemented in the cohort replacement modeling were derived from the higher end of the range in parr carrying capacities reported in the draft QAR Biological Requirements Report.

Results from the analysis of survival improvements required to meet survival and recovery criteria are similar, but consistently lower than those derived in McClure et al. (2000). Those authors used the same spawner series as a starting point for a simple but robust extinction risk assessment (Holmes, 2000). McClure et al. (2000) used a version of the Dennis Model to estimate the required change in annual population growth rate to meet extinction risk criteria. The analyses described in McClure et al. (2000) were restricted to the 1980+ brood years because of concerns that the impacts of the hydropower system were not stabilized for Snake River stocks prior to this period and an assumption that earlier data may have greater bias or uncertainty. The three up-river population data sets ranked the same within each analysis. The level of survival required to reduce extinction risks to less than 5% at 100 years was a third to approximately one half again greater for the analysis using the techniques described in Holmes (2000). Both analyses projected that the survival improvements needed to meet IRL criteria were larger than those that met the 5% extinction risk criteria. The two methods produced results that were closer in magnitude for this criteria.

4.1.2 Sensitivity Analysis

4.1.2.1 *Effect of Carrying Capacity Assumptions.*

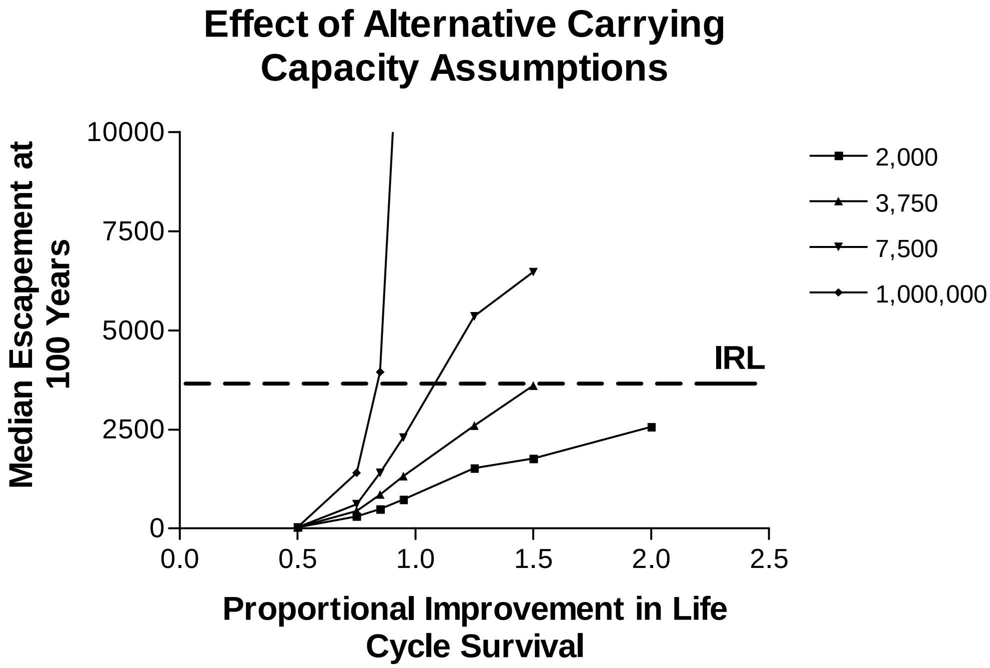

Figure 18 *Relationships between alternative estimates of carrying capacity on the projected median spawning escapement at 100 years as a function of potential survival improvement. Wenatchee spring chinook (w/o Icicle Creek) data used as example. Current estimate of Wenatchee carrying capacity is approximately 4,000 spawners.*

The level of survival improvement necessary to achieve the draft Interim Recovery Level objectives was sensitive to the assumed carrying capacity incorporated into the model (Fig.18). The current estimate of carrying capacity for the Wenatchee (expressed in terms of spawners) is approximately 4,000 based upon the assumptions outlined in the draft Biological Requirements Report. The expected population size at 100 years is a function of the carrying capacity estimate assumed in the modeling as well as the incremental change in survival. Under the assumptions of density independence or a very high carrying capacity and sufficient improvement in survival to achieve a population growth rate greater than 1, the projected population size expands rapidly to unrealistically high levels. As the population approaches carrying capacity additional increments in survival improvement are no longer generating compound benefits. As a result, a larger increase in survival is required to increase the projected population size to a higher target level.

4.1.2.2 *Extinction Risk at Equilibrium Population Growth Rate*

The Wenatchee 1980-94 data set was used for a sensitivity analysis of the projected extinction rate given a range of population sizes and a mean population growth rate of 1. The CRR model described above was used to generate 1000 simulations for different combinations of equilibrium spawner return levels paired with a range of spawner ceiling levels. Three different spawner ceiling levels were used in the analysis: 4000 (roughly equivalent to estimated carrying capacity), 10,000 and 10,000,000 (equivalent to no effective ceiling on spawners). Equilibrium return levels ranged from 250 to 8000, although run sets were truncated if extinction risks fell to lower than .002 at a given ceiling level.

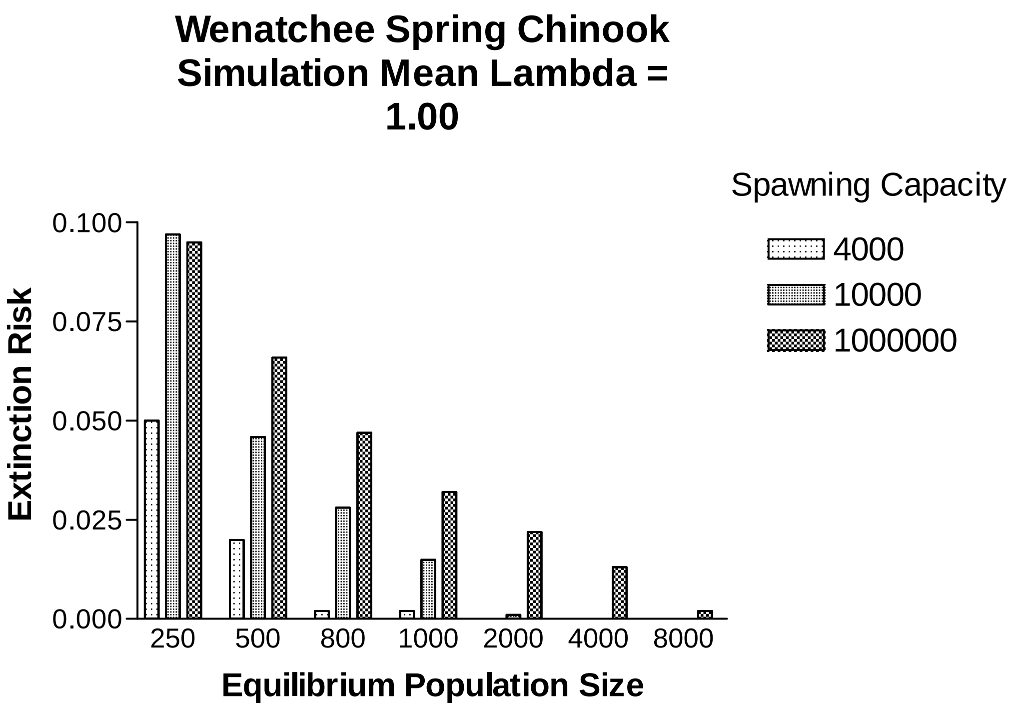

Figure 19 *Projected extinction risk (population to 0 at 100 years) at an average population growth rate of 1.00 as a function of equilibrium spawning run size and assumed ceiling levels on spawner effectiveness.*

Projected extinction risks were related to the assumptions regarding equilibrium levels and spawner ceilings. For a given equilibrium population size, modeled extinction risks were higher the higher the assumed spawner ceiling. At very high spawner ceiling levels, the modeled extinction risk was approximately 5% at an equilibrium population size of 800 and 1% at a population size of 4,000 to 5,000. Given an assumed ceiling level on effective spawner production at 4,000, the equilibrium level associated with a 5% modeled risk is approximately 250, the 1% risk level is on the order of 500-800.

The differences in extinction risk appear to be generated by the increase in survival rates from 1980-94 base levels required to maintain population growth rates at 1.00 given alternative equilibrium levels. At lower ceiling levels, it takes more of an improvement in average life stage survival to overcome the ‘discounting’ effect of the ceiling.

Extinction risk projections under the assumption of no change from current life cycle survivals were not affected by the inclusion of carrying capacity estimates. Carrying capacity does not come into play under the assumption of continued low survivals as a result of the low starting population size and the average downward trend.

Assuming no density dependence is the equivalent of assuming the upper end of the range depicted in Figure 19 above. Ignoring the effects of density dependence at moderate to high escapements can result in misleading conclusions regarding the level of survival increase necessary to meet survival and recovery objectives for listed stocks.

4.1.2.3 *Preliminary Estimates for Recent Year Returns*
The analyses described above were based on spawner to spawner survival rates up through brood year 1994 (5 year old returns in 1999). Adult returns of upriver spring chinook to the Columbia River in 2000 indicate higher than average survivals. Jack returns support an assumption that high survivals will continue for at least one more brood. A sensitivity analysis was done to evaluate the potential impact on base period survival assumptions of alternative patterns in survival for the next 2-4 brood years. Assuming that patterns in return rates to the upper Columbia region will be reflecting in wild stock spawning escapements, we can expect at least 2 years at a return rate of approximately 2:1. Adding those years to the 1980-present data set and assuming that subsequent years are drawn from a distribution represented by the resulting 1980-96 average results in a new average close to the estimated average for 1970-present data series.

Evaluation of the spawner/spawner series for the Wenatchee indicates a high probability of sequential runs of positive or negative values. The CRR model was modified to reflect the degree of year to year correlation in the 1970-present data series while maintaining the appropriate average and variance in the data series (see methods description above). The Wenatchee had the strongest indication of interannual correlation in return/spawner. Incorporating that correlation into model runs based on the 1980-present geometric mean return/spawner did not appreciably change the estimated extinction risk at 24, 50 or 100 years (Table 14). The required improvement in life cycle survival to meet the survival criteria remained roughly the same as projected for the analysis without correlation. The survival improvements to meet recovery objectives were slightly (5-10%) lower with correlation included.

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Table 14: *Effect of considering alternative base period assumptions on; a)upper Columbia spring chinook extinction risks and; b) survival improvements needed to meet survival and recovery criteria.*

Population	**Base (brood years)**	**Extinction Risk (24/48/100 years)**			**% Change in R/S to get Risk Below 5% 48 yrs 100 yrs**		**Change in R/S to meet recovery at 48 years**	**Change in R/S to meet recovery at 100 years**
Wenatchee	1980-94	7%	62%	98%	50%	75%	170%	155%
	1980-**96**	1.3%	24%	71%	15%	40%	115%	102%
	1980-94 ***(correlation)***		*58%*	*98%*		*74%*	*162%*	*155%*
	1970-94	0.2%	15%	73%	20%	35%	95%	90%
	1970-**96**	0.4%	7%	43%	6%	20%	77%	70%
Methow	1980-94	0.3%	16%	50%			105%	95%
	1970-94	1.4%	23%	72%			100%	95%

4.1.2.4 *Uncertainty in Mean Spawner/Spawner Ratios*

The extinction risks and population growth rates estimated in this analysis are based on series of return per spawner estimates for an historical period and age at return information. The estimated population parameters are based on the assumption that the sample geometric mean value of the spawner to spawner return ratio for a particular historical period is an estimate of the underlying or true long-term average return rate. The standard error about the geometric mean return rate for a given annual series reflects the uncertainty regarding the long-term mean return rate. Assuming a normal distribution, a particular value for the average return per spawner can be calculated for various percentiles. Assuming the total variance estimated for the series applies, specific values for extinction risk and for lambda can be estimated for specific percentile values of spawner to spawner ratio using the simulation model as described above. Table 15 summarizes the results for two Wenatchee spring chinook data sets - the 1980 to the present series an the 1970-present series.

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Table 15: *Wenatchee Spring Chinook. Statistical analysis of probability of extinction based on log-normal mean and standard error estimates.*

	Wenatchee Spring Chinook 1980-94 Brood Year Data				**Wenatchee Spring Chinook 1970-94 Brood Year Data**			
Percentile		***Extinction Risk (based on 1,000 model runs for each scenario)***				***Extinction Risk (based on 1,000 model runs for each scenario)***		
	λ	***24 yr***	***48 yr***	***100 yr***	***λ***	***24 yr***	***48 yr***	***100 yr***
.975	1.02	-	1%	3%	1.04	-	-	0.4%
.95	1.00	0.3%	2%	13%	1.01	-	0.2%	2%
.90	0.97	0.3%	5%	31%	1.01	-	0.7%	6%
.75	0.95	4%	22%	73%	0.97	0.2%	0.4%	31%
.50	0.89	12%	59%	98%	0.95	2%	18%	75%
.25	0.81	76%	99%	100%	0.91	5%	43%	95%
.025	0.75	84%	100%	100%	0.87	30%	86%	100%

The approximate confidence limits on lambda and extinction risks are quite wide, consistent with the results of other extinction risk assessments. It is important to note that the projected extinction risks are quite high over a substantial percentage of the potential outcomes. For example using the 1980-present Wenatchee data series, the 95% confidence limits for the 1 100 year extinction risk would be 3% to 100%. However, 90% of the runs projected an extinction risk of 31% or higher. The models indicate that there is a relatively small chance that, from a statistical perspective, the long term extinction risk is minimal given a continuation of the survival relationships prevalent since 1980.

4.1.2.5 *Alternative Criteria*

The results presented above were contrasted against the basic extinction risk criteria used in the 2001 FCRPS Biological Opinion. Alternative criteria for expressing the risk of extinction have been identified for application to the Columbia Basin. Several such measures were used in the PATH process and are described in the methods section above. Quasi-extinction risk measures are generally based on low numeric thresholds. Two variations on this theme are included in this assessment, the risk of falling below 50 spawners over consecutive years, and the risk of falling below a threshold level based on historical performance. As a measure of long-term extinction risk, the percentage of future runs projected to fall below a stock specific estimate of an historical threshold level serves as a criteria.

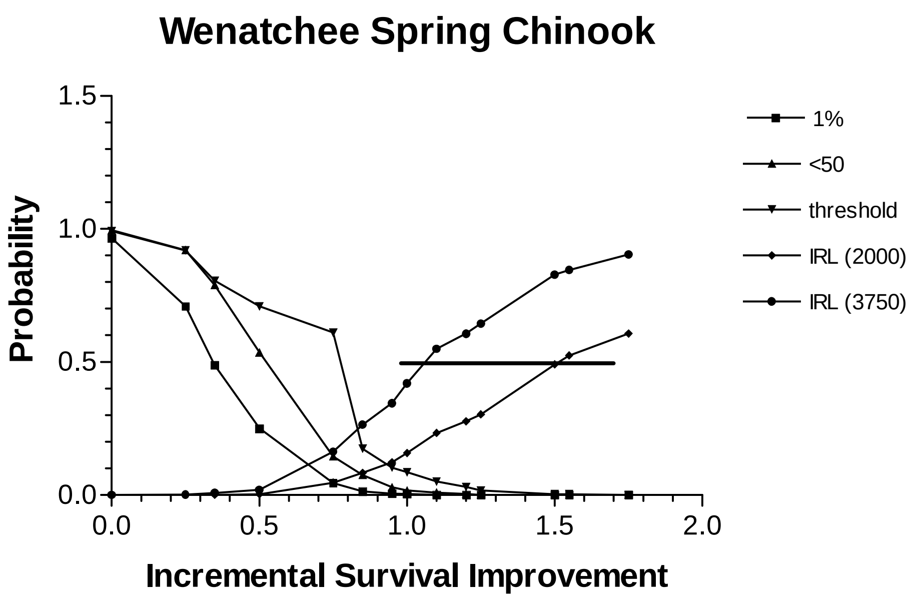

Figure 20 *The projected change in aggregate life cycle survival necessary to meet various risk assessment criteria.*

The results of using different criteria for assessing extinction risk can be seen by plotting the alternative methods on a common graph (Figure 20). The X axis in Fig. 20 represents the proportional increase from base survivals necessary to achieve any particular level of risk given each of the major criteria. In general, the lines representing alternative survival criteria track each other. Given the starting population structure and growth rate characteristics, greater incremental changes in survival are necessary to meet various thresholds at a given current population size. For example, reducing the risk of extinction to below 5% as measured by the frequency of years going to a population level of 1 or less at 100 years requires a positive change of approximately 75% in survival . Given the same relative risk level, 5% at 100 years, using a threshold of 50 fish as a criteria would require roughly a 90% improvement in average survival.

The PATH analyses used a threshold approach to express quasi-extinction risks. The PATH survival criteria was at least a 70% chance of exceeding a lower threshold level. For the Wenatchee example above, an increase in life cycle survival of approximately 85% would be required to meet the 70% threshold criteria at 100 years.

In these analyses, meeting Interim Recovery Levels (IRLs) requires the greatest increase in survival. The estimated IRL for the Wenatchee spring chinook natural run was 3,750. The corresponding risk criteria calls for at least a 50% chance that the 8 year geometric mean escapement would exceed that level at 48 or 100 years. Achieving the IRL criteria would take approximately 155% improvement in survival. To illustrate the sensitivity of this measure to the estimated IRL, a second hypothetical IRL level of 2000 was analyzed using the same model. Meeting that criteria would require approximately a doubling in survival, an increase of 100%.

4.1.2.6 *Alternative Population Dynamics Function: Ricker Model*

The extinction risk assessments described in this report were generated using a simple 'broken stick' population dynamics model. The Ricker spawner recruit model has been used in other historical assessments of spring chinook productivity in the Columbia basin (e.g., Marmorek et al., 1998, Schaller, et al., 2000). The sensitivity of extinction risk results to the form of the stock recruit function was explored using the Wenatchee as an example. Schaller, et al. (2000) fit Ricker functions to basin spring chinook stocks. For the Wenatchee, a Ricker function was fit to a spawner/return data set based upon the same series of redd counts and run reconstructions described in section 2.1 above. The curve parameters reported for the Wenatchee (1970-94 broods) were adapted into the CRR model. The resulting function, along with its accompanying estimate of variation, were used as the basis for a set of stochastic modeling runs. The results of those runs are summarized in Table (16).

Table 16: *Results of extinction risk modeling using Ricker function fit to Wenatchee return/spawner information for 1970-94 broods a = -.37321, beta=0.0000208, variance = .858. (Schaller, et al., 2000)*

Survival Relative to 1970-94	***Extinction Risk (Proportion of 1,000 model runs with <1 fish at 24, 48 and 100 years***			***Average Lambda (50 yrs)***	***Median Escapement of model runs at 48 and 100 Years***	
	24 Yrs	***48 Yrs***	***100 Yrs***		***48 Yrs***	***100 Years***
0.75	3.3%	59.1%	99.4%	.88	-	
0.90	0.7%	15.5%	81.3%	.83	-	10
1.00	0.1%	4.0 %	36.8%	.97	-	23
1.25	0.0%	0.0%	1.2%	1.002	210	193
1.50	0.0%	0.0%	0.0%	1.020	796	661
2.00	0.0%	0.0%	0.0%	1.030	1875	1790
2.50	0.0%	0.0%	0.0%	1.036	2660	2734
3.00	0.0%	0.0%	0.0%	1.039	3435	3420

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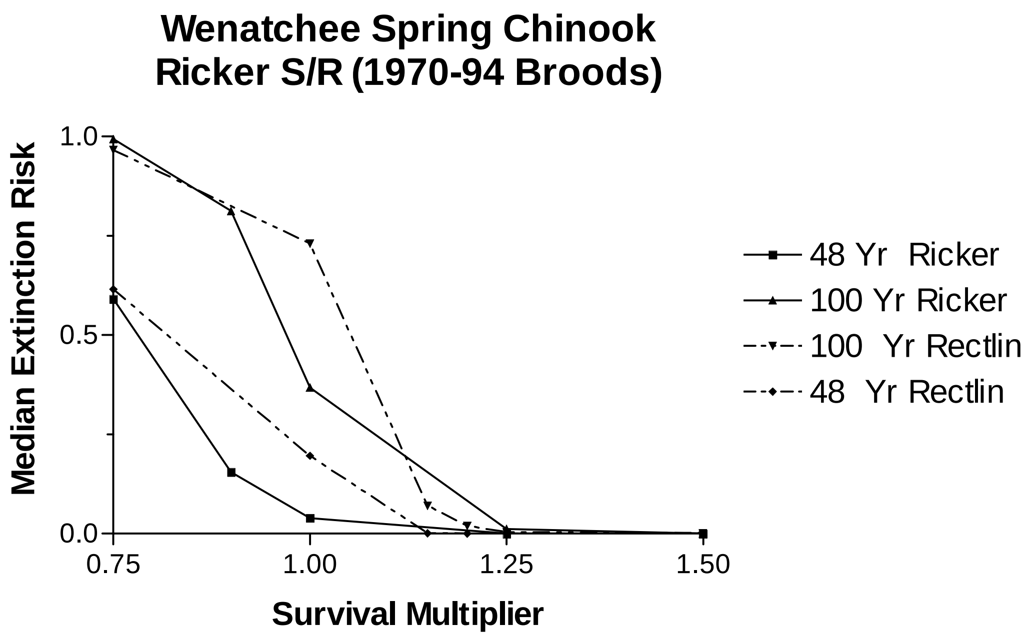

Figure 21 *Comparison of Ricker vs rectilinear (broken stick) production models in terms of the projected relationship between life cycle survival improvement level and extinction risk (measured as the proportion of model runs with 0 spawners at 48 or at 100 years)*

The analyses based on the Ricker model projected lower extinction risks at 100 and at 48 years than did the 'broken stick' (rectilinear) model. In addition, the relative risk of extinction increased more rapidly for the broken stick model than for the Ricker model as survivals declined from the 1970-94 average towards the lower 1980-94 average. Reducing average survivals to levels corresponding to the 1980-94 period resulted in projected similar, and very high, projected extinction risks under both models (Figure 21). The incremental improvement in life cycle survival necessary to get extinction risks below 1% at 100 years were similar for the two analyses - on the order of a 20-25% survival improvement over the 1970-94 base.

The biggest differences in model projections resulting from the alternative stock recruit functions were in terms of the life cycle survival improvements necessary to meet Interim Recovery Level criteria. Roughly a doubling of 1970-94 life cycle survivals would be projected as necessary under the broken stick model to achieve a 50% chance of being above the IRL levels. Using the Ricker function as described above, the relative survival change projected to have a 50% chance of achieving the IRL criteria would be twice as high, a 200% increase over base average survival rates.

4.2 Steelhead

4.2.1 CRR Model Results

Results for the two modeled upper Columbia steelhead runs are summarized in Table 17. The CRR model used for steelhead was similar to that applied to spring chinook. The distribution of historical return rates (1976-1994) was adjusted to reflect recent average harvest rates and used as the basis for simulations. A simple 'broken stick' stock-recruit relationship was assumed. Recruitment from escapements above the breakpoint on the relationship were generated by multiplying the ceiling value times the random variable drawn from the distribution representing year to year variations. Each model run incorporated one of four assumptions regarding the relative effectiveness of hatchery spawners: a) hatchery spawners were equivalent to wild spawners in parr production (effectiveness = 1), b) hatchery spawners were 75% as effective, c) hatchery spawners were 50% as effective and d) hatchery spawners were 25% as effective as their wild counterparts. There is no direct information available for the upper Columbia to gauge the actual relative effectiveness of hatchery spawners. The values above bracket the middle to upper end of a range of estimates from field studies in other locations, given the similarities in timing of hatchery returns into the upper Columbia and the large component of brood stocking from within the area.

Table 17: *Upper Columbia steelhead. Change in spawner to spawner survival projected as necessary to meet survival and interim recovery objectives - all estimates under the assumption of no further hatchery inputs into spawning*.

Stock	**Hatchery Spawner Effectiveness**	**Direct Extinction Risk Criteria**		**50% + Probability of Exceeding draft Interim Recovery Level**	
		<5% Risk of 0 Spawners at 24 Years	**<5% Risk of 0 Spawners at 100 Years**	**48 Years**	**100 Years**
Methow	1.0	0%	***152%***	265%	***265%***
	.75	0%	***115%***	210%	***200%***
	.50	0%	***70%***	140%	***135%***
	.25	0%	***15%***	55%	***55%***
Wenatchee	1.0	0%	***87%***	160%	***160%***
	.75	0%	***67%***	120%	***120%***
	.50	0%	***45%***	95%	***95%***
	.25	0%	***12%***	50%	***50%***

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5 Potential Effect of Actions

Human actions can effect spawner to spawner survival rates for upper Columbia spring chinook at several points in their life cycle. Tributary habitat actions can potentially improve the survival of returning adult spawners as well as the survival from egg to outmigrating smolt. Mainstem passage improvements and estuarine habitat actions could potentially improve survival during the smolt outmigration phase. Such improvements might also translate into reductions in latent mortality later in the ocean life history stages. This section describes the proposed HCP actions and characterizes the potential improvement in survival associated with those actions.[12]

5.1 Proposed Actions

The listed upper Columbia salmon and steelhead migrate through several mainstem Columbia River hydroelectric projects. Nine mainstem dams exist between the uppermost of the upper Columbia stocks (runs into the Methow and Okanagan River systems) and the ocean. Runs from the Entiat subbasin must contend with 8 mainstem hydroelectric projects. Wenatchee River salmon and steelhead runs traverse 7 mainstem dams. Rock Island Dam, located within the upper Columbia region just below the town of Wenatchee, was the first of the mainstem dams to go into place in 1933. 1938 was the first year in service for both Grand Coulee Dam, an impassible up-river block to the upstream migration of salmon and steelhead, and Bonneville Dam. The remaining mainstem dams directly affecting the migration of upper Columbia River runs were came on line between 1953 (McNary Dam) and 1967/68 (Wells and John Day dams).

Two basic questions must be addressed to assess the potential benefits of alternative future hydropower actions towards achieving survival and recovery goals for the upper Columbia salmon and steelhead ESU's.

> What survival levels through the hydropower system corresponding to the historical data series used in the survival and recovery risk assessments described above?
>
> How much improvement in survival over those levels could be attained through alternative hydropower system actions?

5.1.1 Historical Impacts

The survival and recovery criteria described above were based on assessments of stock performance since the early 1960's, with an emphasis on the 1980-94 brood years. Given the basic life history of upper Columbia spring chinook and steelhead runs, the corresponding juvenile series began with the 1982 out-migration. Direct estimates of juvenile out-migration survival are not available on a year by year basis. Limited experimental work in the upper Columbia river in the 1980's combined with Snake River studies that continue tho the present day provide some insight.

Estimates of juvenile survival through mainstem hydroelectric projects are based on a combination

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[12]Appendix 8.1 contains a description of a basic model used in assessing the effects of life stage survival changes on spawner to spawner return rates or annual population growth rate.

of study results. Reach survival estimates - based on mark recapture experiments with releases at one or points within a series of hydroelectric projects and recaptures at some point downstream provide a useful starting point for the historical assessments of survival through the Mid-Columbia PUD projects. Whitney et al. (1997) summarizes the results of branding studies conducted in the early 1980's for the reach including the five Mid-Columbia PUD projects. The studies used hatchery released smolts and The resulting estimate of approximately 14-15% mortality per project (dam+reservoir - Table 2 - Whitney et al.,1997). Passage survival experiments are also reviewed and summarized in Chapman et al (1994 & 1995), Skalski et al (1999), Draft BioOp, draft NMFS White Papers.

Breaking the survival through the hydropower system down into components is helpful in constructing projected improvements associated with alternative future operating scenarios. The reach survivals described above apply to the stretch from the Methow to Priest Rapids Dam. The following discussion will summarize estimated survivals for that reach along with the reach extending from just above McNary Dam to below Bonneville Dam. The estimates used for this assessment reflect data summarized through the PATH and CRI processes.

Migrating juveniles pass through each project through a series of major pathways. One potential pathway is through spill. Studies indicate that this is a relatively high survival route, with an average survival rate of approximately 98%. The proportion of out migrating smolts that pass over the dam via spill is determined by the spill rate over the duration of the smolt out-migration, the proportion of the flow through the project that is spilled, and the relative efficiency of spill for fish passage. Passage efficiency can often be a function of both flow and the proportion spilled. Two other pathways through a particular project need consideration - directly through the turbines, or through a bypass system designed to shunt juveniles from the flow though the turbines.

Passage through the downstream hydroelectric projects (McNary, John Day, the Dalles and Bonneville Dams) is more complex. For 15 out of the 16 years used as a base period for the biological analyses, collection and transportation via barge from McNary has occurred. In recent years, actions triggered by the listing of Snake River spring chinook have affected lower river passage conditions. The following analysis of potential historical survival levels breaks out estimated juvenile survivals into sets corresponding to the upper River and lower River geography.

5.1.2 HCP Actions

A smolt out-migration sampling program has been conducted at Rock Island Dam since the mid-1980's. Daily samples are taken throughout the spring migration. Index counts of composite steelhead and yearling chinook are available for the entire sampling period. Breakdowns into hatchery and wild components are available for steelhead. Hatchery/wild sampling estimates are available for yearling chinook migrants for more recent years although they are considered unreliable because of difficulties in distinguishing between individual hatchery and wild migrants (Chuck Peven, personal communication). Steelhead and spring chinook juveniles have similar run timing past Rock Island Dam (Figure 20). Annually, approximately 95% of each run passes Rock Island Dam between mid-April and mid to late June.

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Run timing information is not directly available for the other projects encountered by upper Columbia spring chinook and steelhead on their outmigrations. Tagging studies indicate that the travel time between projects is on the order of 3-7 days (summary in Chapman et al., 1994). The Rock Island timing curves were extrapolated to the other projects by lagging or advancing the timing by one week.

The proportion of river flow spilled at each project varies as a function of flow, the hydroelectric capacity of the project and the operational regime in effect. The first two factors were the primary determinants of spill levels through most of the years in the historical data series. Deliberate spill operations have become increasingly important as a result of a series of agreements and FERC regulatory proceedings since 1980.

Estimates of historical annual passage for Upper Columbia steelhead and spring summer chinook were generated with a simple model (Figure 23). For each year, estimates of the proportion spilled

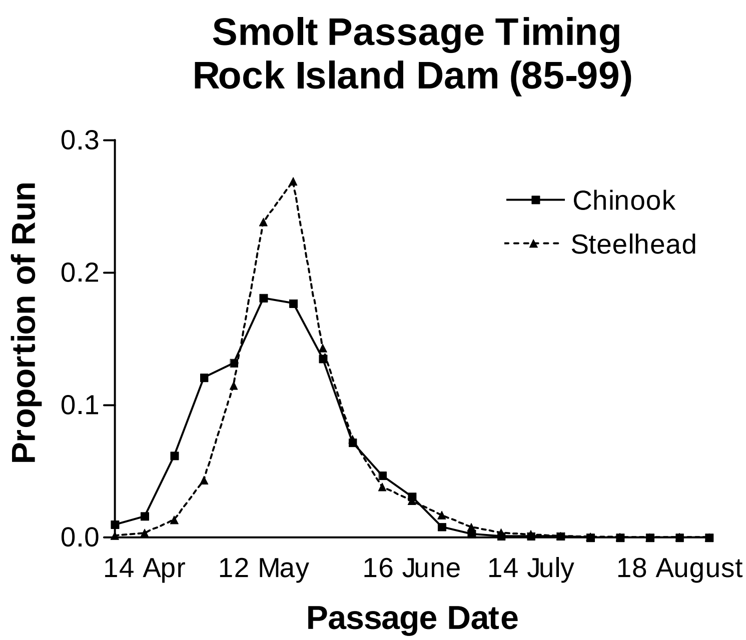

Figure 22 *Average smolt timing at Rock Island Dam. Based on annual smolt trapping studies 1985-99*

during the spring outmigrations were generated using the smolt timing information in conjunction with daily estimates of flow and spill rates. The proportion of smolts passing a project via spill was assumed to be the same as the proportion of flow through the spillways, with one exception. Evaluations have shown that a high percentage of the smolt run (approximately 97%) at Wells Dam passes over the spillway, presumably due to the unique design of the project (e.g., Whitney, et al, 1997). For years prior to 1990, the model described above was applied at Wells Dam. For more recent years (post-1990), it was assumed that 97% of the migration passed the dam via spill. Daily flow and spill estimates for each project were obtained from the Fish Passage Center. The information was summarized on a weekly basis for comparison. Each facility has an upper hydraulic capacity. Flows above that capacity level would be 'released' as spill. Spill levels have been relatively high in recent years as a result of natural conditions, settlement agreements and regulatory actions (e.g., 1995 Federal Hydropower System Biological Opinion).

Mortality Rates

Component passage survival rates from the literature were used in the simple model. Survival estimates summarized in Whitney (1993) were used in the analysis. Survival of juveniles passing over the spill way was estimated as .98. The relative survival of juveniles passing through the turbines was estimated as .89. Reservoir survival was calculated by finding a best fit mortality rate per reservoir mile using the simple spreadsheet model described above and the results of reach survival experiments conducted in 1982, 83, 85, 86 and 87 (e.g., Bickford, 1997). The reach survival estimates for each year were paired up with corresponding model survival estimates. The fitting routine was adjusted to incorporate an additional 60 km of passage route for the 1985, 86 and 87 reach survival estimates corresponding to the fact that the release point for these experiments was 60 km upstream of the mouth on the Methow River. The Excel routine 'Solver' was used to find the average reservoir mortality per mile that minimized the sum of squares for the difference between the model estimates of reach survival and the experimental estimates. The best fit estimate of reservoir survival, calculated on a per project basis was .96.

Annual Passage Survival: Mid-Columbia Projects

The results of applying the simple model are summarized in the attached tables. Excluding Wells Dam, spring chinook per project survivals averaged .87 for the 1982-96 migration years corresponding to the base period used for survival analyses in this study. Steelhead survival rates were calculated to be slightly higher than those for spring chinook. The difference in aggregate survival rates between the two species was the result of small but consistent differences in population run timing relative to specific daily spill schedules for each year.

The draft HCP sets long term objectives for passage survival through the Mid-Columbia PUD projects. The goal for each project is based on achieving no less then 91% survival at each project for juveniles and adults combined. The 9% mortality allowance is intended to be addressed through a combination of supplementation and habitat improvement actions.

Assuming a 91% passage goal, the minimum average juvenile passage survival can be calculated given an assumption regarding adult migrant mortalities. In the absence of direct estimates for the upper Columbia, the draft HCP incorporates an interim value of 2% adult mortality per project attributable to the effect of the hydropower system. Average juvenile survivals must exceed 93% given the assumption of a 98% adult survival rate. The combined effect of achieving the passage objectives at each of the five Mid-Columbia projects varies as a function of the number of projects between the tributary of interest and the ocean (Table 18).

Table 18: *Summary of historical (1982-96 passage year) average project juvenile survival rates calculated from annual weighted spill fractions and run timing information.*

	Wenatchee		Entiat		Methow/ Okanagan	
Mid Col. Projects	**3**		**4**		**5**	
	Sthd	***Spr***	***Sthd***	***Spr***	***Sthd***	***Spr***
Priest Rapids	.886	.869	.886	.869	.886	.869
Wanapum	.886	.875	.886	.875	.886	.875
Rock Island	.878	.870	.878	.870	.878	.870
Rocky Reach			.871	.865	.871	.865
Wells					.913	.890
Cumulative Impact	***.690***	***.662***	***.633***	***.573***	***.549***	***.511***
HCP Cumulative (.928 per project)	***.80***		***.74***		***.69***	
Projected Survival Improvement	**1.16**	**1.21**	**1.23**	**1.30**	**1.25**	**1.35**
Habitat Component	***1.06***		***1.08***		***1.10***	
Projected Composite HCP Improvement	**1.23**	**1.28**	**1.33**	**1.40**	**1.38**	**1.49**

For comparison, a rough estimate of reach survival from each of the upper Columbia tributaries through the Mid-Columbia Reach (tributary to below the site of Priest Rapids Dam) was generated. No direct information is available regarding juvenile passage survivals in the upper Columbia prior to dam construction. Historical estimates of spring chinook and steelhead survival are available for the 512 km reach from the Whitebird trap to Ice Harbor Dam in the Snake River system prior to the construction of the intervening lower mainstem Snake River dams (e.g., Smith, et al. (1998). The average survival rate per km for the free flowing portion of that reach was .99967 per km. Applying that survival rate to the reach from each of the upper Columbia tributaries to a point below the Priest Rapids dam site results in an average per project unimpounded reach survival estimate of .98 to .99 (Table 19). The estimated base period survival rates for the same reach are included in Table 18. The ratio between the two estimates represents the potential improvement in survival of removing the direct impacts of the Mid-Columbia River hydroprojects. PIT tag experiments in the Snake River support the hypothesis that the hydroelectric projects effect bot the immediate survival of migrating juveniles and the survival of migrants after they enter the lower river and nearshore ocean. Indirect mortality is very difficult to quantify. Equivalent analyses that might substantiate or refute the existence of delayed hydropower mortalities for upper Columbia migrants do not exist.

Table 19: *Estimate of unimpounded reach survival for the upper Columbia. Snake River survival per km estimates applied to the distance between tributary mouth and the Priest Rapids Dam site.*

	River Kilometer	**Distance to Priest Rapids**	**Tributary to Priest Rapids Survival / Ratio to Base**			
			Spring Chinook		**Steelhead**	
			.99969 per km		**.99967 per km**	
Methow	843	204	.94	1.84	.93	1.69
Entiat	779	140	.96	1.68	.95	1.50
Wenatchee	753	114	.97	1.47	.96	1.39
Priest Rapids	639					

5.1.3 FCRPS Improvements

Existing estimates of survival through the Lower Columbia were adapted for the purposes of this analysis. The historic passage survival estimates compiled through the PATH process were used to estimate average base period survivals through the reaches from McNary through Bonneville Dams. The PATH March 1998 report includes a number of diagnostics generated with the two passage models FLUSH and CriSP. Model estimates of historical passage survivals are similar. One set of runs breaks down the passage survival from Lower Granite Dam to below Bonneville Dam into two components - survival from Lower Granite through John Day pool, and survival from John Day forebay to the tailrace of Bonneville Dam (Marmorek & Peters, 1998 App. A).

An estimate can be calculated of the average cumulative lower river passage survival during the selected base years for this assessment based upon the PATH information:

The average per project survival (.87) for the John Day to Bonneville reach was assumed to apply to the two lower projects (Dalles & Bonneville) for upper Columbia spring yearling migrants. The average per project survival from Lower Granite through John Day project (.81) was assumed for survival through the John Day project for upper Columbia yearling migrants. McNary project survival was assumed to be equal to the an average of upper Columbia project survival and John Day project survival (.85). Table 20 summarizes the resulting cumulative survival estimates for base period runs as well as for the options described above. The resulting aggregate estimate of in-river survival from McNary to below Bonneville is .515.

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A portion of the yearling chinook run at McNary Dam was captured and transported to below Bonneville via barges from 1977-1994. As a result of concerns regarding the relative survival of transported Snake River migrants from the McNary collection operations, the practice was discontinued by the 1995-98 Federal Hydropower System Biological Opinion. The estimated base period average survival cited below incorporates transportation assumptions. Direct estimates of the proportion of upper Columbia migrants captured and transported are not available. An estimate of the collection efficiency can be inferred from recent PIT tag detection patterns. PIT tag detection efficiencies at McNary Dam are relatively low, approximately.18-.20 (John Williams, personal communication). No direct estimates of the potential delayed mortality associated with collection and transportation of juveniles. Detailed analysis of Snake River PIT tag data for recent years indicates a relatively high rate of loss associated with the bypass system at McNary Dam (NMFS 2000a). For this analysis, a delayed mortality of .20 was assigned to transported component of upper Columbia spring migrants (equivalent to D = .80).

Table 20: *Summary of Lower River Passage Survival Calculations. Composite survival equals the weighted average of transported and in-river migrants.*

<table>
<tr><th rowspan="3"></th><th colspan="2">In-River</th><th colspan="3">Transport</th></tr>
<tr><th rowspan="2">Proportion In-River</th><th rowspan="2">Survival</th><th rowspan="2">Proportion collected</th><th colspan="2">Survival</th></tr>
<tr><th>D=1</th><th>D=.8</th></tr>
<tr><td>McNary Project</td><td>.50</td><td>.85</td><td>~ .50</td><td colspan="2">.85</td></tr>
<tr><td>John Day</td><td></td><td>.85</td><td rowspan="3"></td><td colspan="2" rowspan="3">.98 (barge)</td></tr>
<tr><td>Dalles</td><td></td><td>.87</td></tr>
<tr><td>Bonneville</td><td></td><td>.87</td></tr>
<tr><td></td><td></td><td>.547</td><td></td><td>.833</td><td>.666</td></tr>
<tr><td>McNary to Below Bonn Composite Survival:</td><td></td><td></td><td></td><td>.690</td><td>.607</td></tr>
</table>

A number of options for configuring or operating the federal hydroelectric projects on the lower mainstem of the Columbia River are under consideration. For the purposes of this analysis, four alternatives have been included in the analysis.

1. *93% Survival Objective*: Improve passage at the lower river projects so as to meet the same objectives as set forth in the draft HCP for upper river PUD projects.

2. *93% Survival plus John Day drawdown*: Implement John Day drawdown and meet the 91% objective at each of the remaining projects.

3. *McNary Transport plus 91% Project Survival*: Re-establish barge transport from McNary Dam plus meet 91% survival objective at lower projects.

4. *Aggressive In-river Improvements*: Maximum survival improvements at each of the lower river projects as developed through the federal caucus initiative (2000 FCRPS Biological Opinion hydropower measures).

Table 21 summarizes the aggregate effects of each of these options on projected average survival through the lower river projects. Given the lack of information on delayed mortality of transported upper Columbia origin yearling chinook or steelhead smolts, two different assumptions were included: no delayed mortality attributable to transport (Direct Survival), and 80% relative survival for transported fish vs in-river migrants after release below Bonneville Dam.

Table 21: *Summary of lower river project impacts and relative changes in survival under alternative actions.*

Scenarios	**Direct Survival to Below Bonn**		**Direct Survival to Below Bonn Adjusted for D = .8**	
	McNary - Bonneville Survival	***Proportional Change from Historical***	***McNary - Bonneville Survival***	***Proportional Change from Historical***
1980-94 Historical	.690	---	.607	--
1980-94 Historical (no trans)	.547	***0.79***	.547	***0.90***
A. Meet HCP Juvenile Passage Goal at Lower River Projects	.742	***1.07***	.742	***1.22***
B. A + John Day Drawdown	.799	***1.16***	.799	***1.32***
C. A + McNary Transport (Collection Eff = 50%)	.816	***1.18***	.733 .	***1.21***
D. Aggressive In-River	.664	**0.96**	.664	**1.09**

The option labeled Aggressive In-River captures the projected survival improvements associated with the Reasonable and Prudent FCRPS management alternative described in the FCRPS 2000 Biological Opinion (NMFS 2000b). The net effect of the Biological Opinion operations on the survival of upper Columbia River migrants is dependent upon assumptions regarding delayed mortality of transported fish. Assuming that there is no delayed mortality for transported fish, the projected impact of the lower river federal projects under the FCRPS Biological Opinion operations on migrants from the Upper Columbia River is for a small increase (4%) in mortality over the base average. Assuming that there is a delayed mortality of 20% - equivalent to estimates for the Snake River spring chinook before recent updates , the FCRPS BioOp operations would have a modest positive effect (+9%) over the base period average.

5.1.4 Habitat, Harvest and Hatchery Improvements

The major objectives of the QAR process has been to clearly elucidate the current status of the listed upper Columbia River chinook and steelhead populations, to identify the necessary levels of change in survival required to meet extinction risk and recovery criteria, and to assess the potential contributions of actions proposed under the HCP to those needed changes. The following sections describe the conditions or actions in habitat, harvest and hatchery arenas that are can be considered as part of the assessment of future actions. Some of these actions are directly called for in the draft Upper Columbia HCP, others have been implemented or recommended in related ongoing processes (e.g. Section 7 consultations on WDFW Upper Col. Hatchery programs).

5.1.4.1 *Habitat Strategies*

Regional biologists have reviewed habitat problems in the Wenatchee, Entiat, Methow and Okanagan watersheds and have developed recommended priorities relative to potential benefits for the region's anadromous fish stocks (Bugert et. al. (1998). The reviews were done using the general format of the Ecosystem Diagnosis and Treatment approach (Lichatowich et al. 1995). Under this approach, specific watersheds are reviewed to determine the current vs historical capability of supporting a range of life history types for each anadromous species.

The proposed approach under the HCP puts the highest priority on habitat protection for those stocks that are currently performing relatively well. Habitat restoration activities would be prioritized towards those population units that are either performing poorly or are currently extirpated, but that have significant potential. Within those categories, the HCP states that "..the highest priority for maintaining biological productivity will be to allow unrestricted stream channel diversity and flood plain function."

The habitat reviews developed in support of the draft HCP include specific recommendations for actions within each of the four major watersheds in the region.

> ***Wenatchee River:*** Both habitat protection and restoration priorities focus on protection and restoration of stream channel diversity and complexity (including riparian vegetation) in the lower reaches of the river. The second set of priorities focus on restoration of functioning rearing/overwintering areas further up in the river system.
>
> ***Entiat River:*** Focus similar to that in the Wenatchee. Protection of bottom land side channels throughout the drainage and restoration of natural stream channel functions in the lower reaches of the system are identified as priorities. The draft recognizes that the restoration of lower river function in the Entiat will need both a short-term and a long-term strategy, particularly given the current lack of inputs of large woody debris into the area.
>
> ***Methow River***: The draft recommendations identify chronic low flow/high temperature conditions in the lower Methow River affecting summer rearing and passage as a major problem. A pilot plan for restoring in-stream flows in sections of the Methow basin has been developed. The remainder of the specific recommendations for the Methow focus on restoration of natural stream functions in specific areas throughout the drainage.

> ***Okanagan River***: Habitat in this drainage is the most degraded of the four major watersheds in the region. The recommendations include an emphasis on protecting existing riparian corridors and restoring natural stream functions. Additional recommendations include a call for an assessment of sediment dynamics in the drainage.

The Draft HCP provides a mechanism for directing PUD funding towards anadromous fish habitat protection and restoration priorities in the upper Columbia basin. A goal of the proposed program is to generate survival improvements through these actions that would be the equivalent of a survival improvement of 2% per project for each tributary run.

Additional habitat improvements in the upper Columbia basins are possible. Opportunities for focused effort either have or are being identified through various local, state-level or national processes. The 2000 FCRPS Biological Opinion calls for substantial improvements in population survival through actions to improve life stage survivals in the tributary, mainstem and estuarine habitats of listed stocks. Quantifying the potential effects of habitat actions outside of those directly incorporated into the HCP process is a task set for the next phase of the recovery planning effort.

5.1.4.2 *Harvest Management Strategies*

Harvest impacts on both of the listed upper Columbia River ESUs are dominated by in-river fisheries. Until the early 1970's upper Columbia spring chinook were harvested along with returning Snake River stocks in lower river commercial and sports fisheries (WDFW, 1999). Harvest rates in those fisheries were on the order of 30-50% per year. Fisheries were curtailed significantly in the early 1970's in response to declines in returns and recognition of treaty harvest needs. In recent years harvest rates have been reduced further in response to listing under ESA.

Steelhead harvest rates in lower river commercial fisheries were relatively high through the 1960's. Direct commercial harvest of steelhead in non-indian fisheries was eliminated by legislation in the early 1970's. Incidental impacts in fisheries directed at other species continued in the lower river, but at substantially reduced levels. In the 1970's and early 1980's recreational fishery impacts in the upper Columbia escalated to very high levels in response to increasing returns augmented by substantial increases in hatchery production. In 1985 steelhead recreational fisheries in this region (and in other Washington tributaries) were changed to mandate release of wild fish. Treaty harvest of summer run steelhead (including returns to the upper Columbia) occurs mainly in mainstem fisheries directed at up-river bright fall chinook. Harvest rates on upper river spring chinook and steelhead have been cut back substantially from historical levels. The basic analyses described above assume that 1980-94 brood average harvest rates (encompassing incidental sport and commercial catches) would continue into the future (approximately 9% annual harvest rate for spring chinook, 16% for steelhead). More recent harvest agreements have resulted in combined harvest rates that are, on the average, below the levels used in this analysis.

Future analyses should incorporate more detailed harvest rate assumptions corresponding to ‘sliding scale’ harvest management schedules. Such schedules would reduce harvest impact below recent average levels in years with relatively low returns while allowing for increments of additional harvest impacts when runs are relatively high.

5.1.4.3 *Hatchery Strategies*

The initial modeling assessments have focused on simple representations of the supplementation strategies provided in the draft HCP supporting materials and on alternative assumptions regarding the relative effectiveness of hatchery spawners. More detailed analyses of supplemenation strategies in general are under development through the CRI process. The simplified modeling approach described above can be used to generate some insights into the potential effects of alternative hatchery strategies.

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6 Preliminary Action Analysis

A major purpose of the QAR analysis is to provide information on the potential effect of the draft Mid-Columbia Habitat Conservation Plan on extinction risks and recovery possibilities for upper Columbia listed stocks. The analysis is also tasked with identifying the level of additional survival improvement (if any) necessary to achieve survival and recovery objectives for these runs. The results described below are based upon the data, assumptions and analyses described in previous sections of this report.

The central focus of this section is on three questions:

1. How would achievement of the HCP passage and habitat improvement objectives at the five Mid-Columbia PUD projects affect extinction risk and recovery probabilities?

2. How would the combination of meeting the HCP passage/habitat improvement and FCRPS passage/off-site mitigation objectives affect extinction risk and recovery probabilities?

3. Assuming that both Mid-Columbia HCP goals and FCRPS Biological Opinion population performance standards are met, what additional (if any) survival improvement would be required to achieve basic survival and recovery criteria for each population?

In previous sections, simple population models combined with time series of stock-recruit data were used to generate estimates of extinction risks and of the change in survival necessary to meet basic criteria reflecting population survival and recovery needs. Section 5 of this report describes the relative change in life stage survival represented by the HCP goals and objectives as well as for some alternative approaches for managing lower river hydropower impacts. The combined effects of the potential survival improvements from the lower Columbia federal hydropower projects and those that could be gained by meeting the draft HCP survival objectives can be calculated through multiplication, assuming a simple extension of the CRR models used in the analysis.

1. The life cycle of the listed populations can be represented by a simple multiplicative model:

$$SP(t) = \text{sum}\ (A(n) * f(SP(t-n))*(b1*SS)*(b2*SM)*(b3*SEO)*(b4*SA))$$

Where SP(t) = the spawners in year (t)
A(n) = the fraction of returns at age n
F(SP(t-n) = parr produced as a result of spawners in year (t-n) - includes density dependence
SS = base survival from parr to smolt migration,
b1 = relative change in survival SS due to potential actions affecting tributary habitat

SM= base down-river juvenile migration survival from tributary to below Bonneville
b2 = relative change in average survival SM due to improvements at hydropower

projects

SEO= base average estuarine/ocean survival to adult return
b3= relative change in average survival SEO due to improvements

SA= base average survival from river mouth to spawning grounds, reflects average harvest, passage, prespawning mortality rates
b4= relative change in average SA due to harvest management, adult passage actions

2. Density dependence of the populations can be represented by a simple ‘broken stick’ model (consistent with description in section 3.3, Figure 17) where the average number of smolts produced pe r spawner is a constant below a threshold related to the amount and quality of habitat available to each population. Above that threshold, the average production of smolts is a constant. This approach assumes that the mechanism resulting in density dependence operates in the spawner to parr life history phase.

3. Actions to improve survival result in an incremental change in average survival at a particular life history stage, but the level of year to year variation about the average remains the same.

As a result of these assumptions, the cumulative effect of improvements at one or more life history stages can be estimated by multiplying the relative effects against one another. For example, the cumulative effect of a 50% improvement in survival in the parr to juvenile migration phase and a 25% improvement in juvenile passage survival would be 1.50 X 1.25 = 1.875, or an 87.5% improvement in life cycle survivals.

6.1 Spring Chinook

The projected impact on survival and recovery criteria of achieving 1)the Mid-Columbia hydropower and habitat improvement objectives; 2)the HCP objectives plus the FCRPS objectives established in the 2001 FCRPS Biological Opinion are summarized in Table 24 for upper Columbia spring chinook populations. The model results indicated that the Wenatchee required the most improvement in survival to meet objectives (the Okanogan basin was not analyzed due to the lack of sufficient population data).

Alternative future scenarios are represented in this analysis by three different sets of historical information. Assuming that future conditions would be better represented by the more recent time series of return rates (1980-94 brood years) results in a more conservative, higher, estimate of extinction risks. Using this time series corresponds to assumptions that ocean/climate conditions have degraded, perhaps in response to global warming trends, and that we should not expect to see good return years as frequently as in the longer term data series. Use of this series would also be more representative if there is a delayed effect of passage through the hydrosystem or of hydrosystem operations on survival in the estuary/early ocean life history stage.

The most optimistic future scenario analyzed assumes that future conditions can best be represented by the time series of return/spawner data going back through the 1960 brood. This set of assumptions would apply if there are long-term (30-40 year) cycles in productivity and if there has been no substantial delayed effect on estuarine/ocean survivals or post-migration spawning mortalities due to Columbia River hydropower system development or operations.

The 1970-1994 data series represents an intermediate data set. For the upper Columbia, the number of dams directly affecting passage conditions were in place for essentially the entire period and the major reduction in harvest impacts occurred at the very beginning of the series. Using the 1970-94 period as a base results in projected extinction risks that are less than derived using the 1980-94 series.

Assuming that the cumulative effect of other survival components remain at base period levels, the relative improvement in survival represented by the HCP goal can be directly related to the required survival improvements described in section 4.0. The projected effect of meeting both the HCP and the FCRPS goals can be estimated by multiplying the survival improvements projected for each component, noting that there are two estimates associated with the FCRPS improvements reflecting alternative assumptions regarding delayed mortality of smolts that were transported from McNary during the base period (up through brood year 93). The results of the comparisons are summarized in table 25 and described below.

6.1.1 Effect of HCP Survival Improvement

The estimated direct survival gains projected for meeting the Mid-Columbia HCP passage and habitat mitigation objectives are described in section5.2.1. For each of the three spring populations, the necessary changes in survival to achieve identified survival and recovery criteria are summarized in section 4.0. These assessments assume that harvest levels will remain at recent average levels, that other survival components (e.g., natural survival through estuary and ocean) will remain the same as in the appropriate base period - either 1960 to 1994 brood, the 1970-94, period and the 1960-94 time series. As noted above, it there is a great deal of uncertainty regarding natural survival due to annual environmental fluctuations.

1980-94 Brood Year Base

Under the assumptions that harvest remains at current levels and the future tributary/ocean/adult survivals can be represented by the 1980-94 data series, achieving the HCP passage/habitat survival goals would exceed the improvement levels needed to reduce projected extinction risk to less than 1% at 100 years for only the Methow population. Additional survival improvements of 48% and 19% would be required to meet the 100 year extinction risk criteria for the Wenatchee and the Entiat populations, respectively. The corresponding requirements to reduce model extinction risks to below 5% at 100 years for these two stocks were 37% and 12%. While achieving HCP goals contributes to reducing the survival improvement necessary for meeting recovery objectives, additional measures would be required to meet the 48 year and 100 year criteria for all three modeled populations. The projected improvements in survival required to meet the 48 year criteria after taking the HCP improvements into account ranged from 38% for the Methow to 115% for the Wenatchee. Requirements for reaching the recovery objectives within 100 years after consideration of the HCP *improvements* ranged from 31% to 99% for the same populations.

1960-94 Brood Year Base
Under the assumptions that harvest remains at current levels and that future tributary/ocean/adult survivals can be represented by the 1960-94 data set, achieving the HCP passage survival goals would exceed the improvement levels needed to reduce extinction risk to less than 1% at 100 years for all three stocks. Under this scenario, the 100 year recovery criteria would also be met without additional survival improvements at either the 1% or the 5% risk levels. The recovery 48 year recovery criteria would be met for the Entiat under this scenario. A small (1%) additional improvement in survival would be required to meet the criteria for the Methow and a 9% improvement would be required to meet the 48 year criteria for the Wenatchee.

1970-94 Brood Year Base
Under the assumptions that harvest remains at current levels and the future tributary/ocean/adult survivals can be represented by the 1970-94 data series, achieving the HCP passage/habitat survival goals would exceed the required improvement levels to meet 100 year extinction risk criteria for two of the populations, Methow and Entiat. The Wenatchee would require and additional survival improvement of 5-15% to reduce the risk of extinction to less than 5% or1%, respectively. All three populations would require additional improvements to meet the 48 and 100 year recovery criteria. The Wenatchee would require the largest improvement - 48% to meet the recovery criteria at 100 years, 52% to exceed the criteria at 48 years. The Entiat would require 16% and 9% improvements, the Methow 34% and 31% to exceed the 48 year and 100 year criteria, respectively.

To summarize, model simulations indicate that incorporating the assumption that HCP passage and survival goals are met results in reductions in risk of extinction. However, the survival improvement resulting from meeting those objectives alone does not reduce the risk of extinction below 5% at 100 years nor does it result in achieving the Interim Recovery levels of abundance, if climate/environmental conditions that prevailed between 1980 and 1996 continue. The probability of both reducing the risk of extinction and reaching interim recovery levels is much higher if the goals of the HCP are met AND the effects of broadening the range of climate/environmental conditions to encompass 1960 to 1996 are considered.

For reference, the free-flowing river passage survival estimates summarized in Table 25 can be compared against the survival improvement levels required to meet the criteria. The ratio of the free-flowing river survival estimates and the baseline passage survival estimates represents the theoretical improvement that could be achieved through eliminating estimated direct mortality due to the Mid-Columbia projects. This approach does not address any delayed mortality that might be expressed after juveniles pass Priest Rapids Dam. Under the assumption that the 1980-94 survival conditions continue, achievement of passage survival improvements up to the level estimated for free-flowing conditions would not meet IRL criteria for any of the three stocks. Assuming that the equivalent of free-flowing passage through the Mid-Columbia reach is achieved and that natural survival components are at 1970-94 levels, the IRL requirements for the Entiat would be met, but additional survival improvements would be required to meet criteria for the Methow and the Wenatchee.

6.1.2 Effect of HCP and FCRPS Actions

There are two components of the 2000 FCRPS Hydropower Biological Opinion that could potentially improve survivals for upper Columbia stocks: the plans for for improved passage conditions at lower river mainstem projects and the identification of specific 'off-site mitigation actions. The impact of changes in the hydropower system as a result of the Biological Opinion is difficult to estimate and depends upon estimates of transport survival/mortality from McNary Dam. Transportation from McNary was part of base period operations. It was discontinued as a result of the previous FCRPS Biological Opinion (1995). The 2000 FCRPS Biological Opinion specifies changes at the lower river projects that are designed to increase in-river passage survival. The impact of those changes on passage survival, relative to the historical base period, determines the 'multiplier' for passage survival. Given the fact that a significant proportion of the run to McNary was transported historically, the net effect of the changes depends upon the relative survival and the proportion of fish that were transported in the baseline years. As described above, there are no solid estimates of delayed mortality effects due to transport from McNary. Two scenarios were explored in section 5.2.- one set in which delayed mortality was assumed to be 20% (D = .8), the other in which there is no delayed mortality (D = 1). If D=.8, the net effect on passage survival of hydropower improvements from Priest Rapids Dam down river would be on the order of 9-10%. If D was historically 1.0, in other words no differential delayed mortality of Upper Columbia origin fish, then the FCRPS actions would represent a net decrease in survival from the base period.

The second component of the FCRPS Biological Reasonable and Prudent Action involve off-site mitigation or further federal actions to improve survivals through activities that increase life stage survivals in the tributary, during juvenile migration or during the adult life history stage. The 2000 FCRPS Biological Opinion identifies target survival improvement levels - offsite Performance Standards - for each of the listed ESUs. Table 22 lists the additional improvements in life cycle survival that would be necessary to meet FCRPS survival and recovery objectives under the range of alternative base period assumptions. The FCRPS Biological Opinion calls for an aggressive program to identify and implement survival improvements for listed salmon populations. The potential for improvement in the tributary and estuary/early ocean life history phase is highlighted, and the federal action agencies are tasked with working to identify ESU specific strategies by late 2003. The FCRPS Biological Opinion encourages the action agencies to work with state, tribal and local jurisdictions in developing action plans to achieve the off-site mitigation performance standards. At this time, the potential survival gains for upper Columbia listed runs that could result from FCRPS related activities or from actions implemented as a result of other federal Biological Opinions are not known.

To provide perspective on the potential targets of off-site mitigation activities, figures 22 and 23 illustrate the combined effect of meeting Mid-Columbia HCP passage and survival goals along with additional survival improvements equivalent to estimates of base period direct impacts of the FCRPS system. Achieving survival improvements equivalent to the estimated direct impact of the FCRPS plus the improvements called for in the draft HCP would project to meet basic survival and recovery criteria for the Methow and Entiat runs under all of the base period scenarios. The Wenatchee population model based on the 1980-94 brood year return/spawner series is the most conservative of the data sets used in this analysis - an additional survival improvement of approximately 40-50% would be required to meet the survival and recovery objectives under this

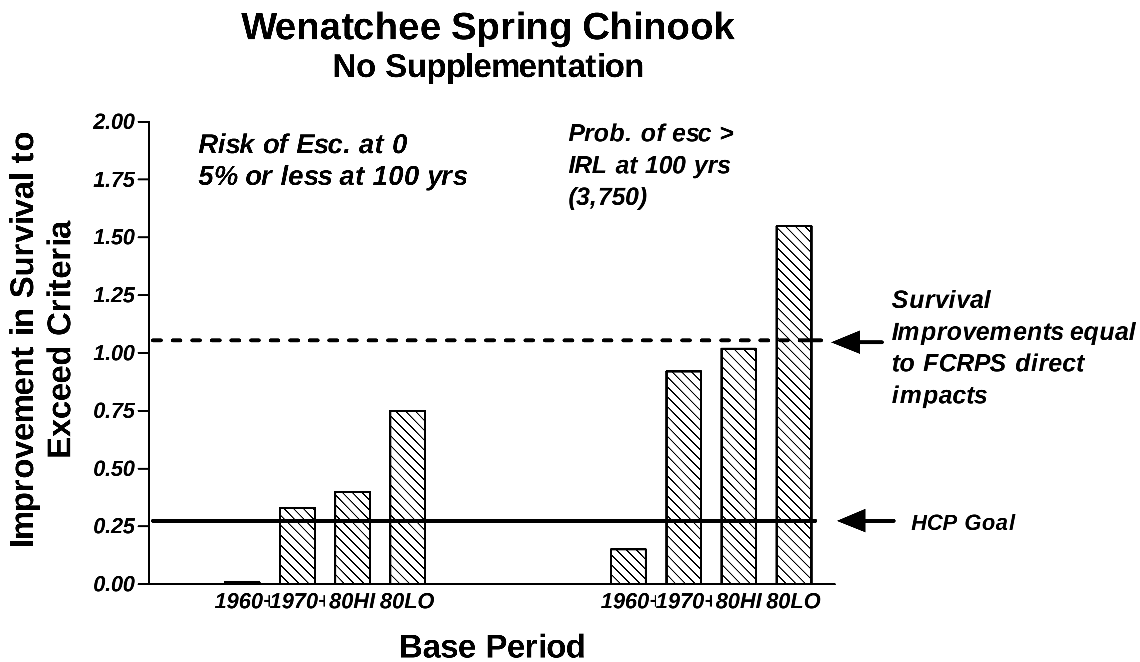

Figure 23 *Wenatchee spring chinook model results. Bars: survival improvements needed to achieve survival and Interim Recovery Level (IRL) criteria under different base period scenarios. Solid lines projected improvement if HCP goals are met at all Mid-Columbia projects. Dashed line: HCP goals plus FCRPS survival improvements equivalent to estimated direct impacts.*

scenario. Figure 25 includes and additional scenario run for the Wenatchee. Preliminary estimates of the 2000 and 2001 returns were used to add two additional years to the recent data series, expanding it to 1980-96 brood years. Both of the recent return rates were higher than the original series average, resulting in an increase in the geometric mean return per spawner. If this expanded recent data series is representative of future conditions, the combination of meeting HCP goals, FCRPS passage improvements and off-site improvements equivalent to the direct impacts in the FCRPS will exceed survival and recovery objectives for the Wenatchee model population.

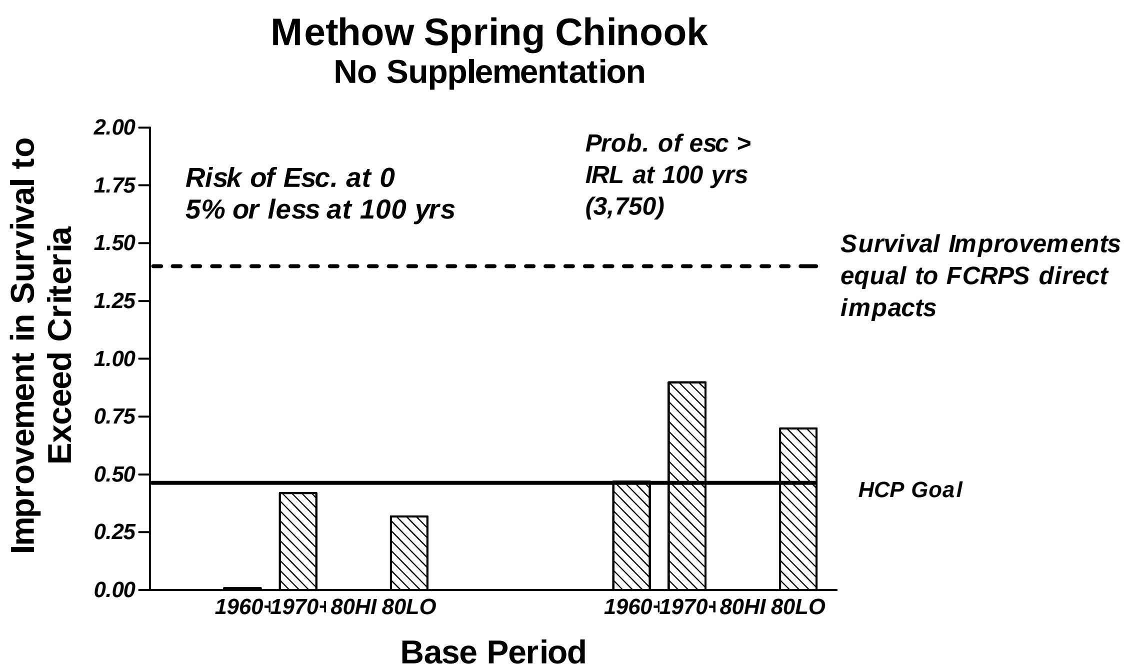

Figure 24 *Methow spring chinook model results. Bars: survival improvements needed to achieve survival and Interim Recovery Level (IRL) criteria. Solid lines projected improvement if HCP goals are met at all Mid-Columbia projects. Dashed line: HCP goals plus FCRPS survival improvements equivalent to estimated direct impacts.*

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Table 22: *Summary of projected improvements over 1980-94 base survival estimates needed to meet survival/recovery criteria for the three spring chinook populations. Estimates corresponding to three different time periods representing a range of possible future climate/environmental conditions are included. Additional survival increments AFTER HCP goals and FCRPS Hydropower survival improvements are expressed as a range reflecting alternative assumptions regarding the relative survival of transported fish (D = 1 or .8)*

Baseline R/S	**Survival Improvement to Reduce Extinction Risk to < 5% ,1% @ 100 Years**						**Survival Improvements for 50% probability of being ABOVE Interim Recovery Level @ 48 & 100 Years**					
	From 1980-94 Baseline		***After HCP***		***After HCP + FCRPS Hydro*** *(1980-94 D =1,.8)*		***From 1980-94 Baseline***		***After HCP***		***After HCP + FCRPS Hydro*** *(1980-94 D =1,.8)*	
	<5%	*<1%*	*<5%*	*<1%*	*<5%*	*<1%*	*48 Yr*	*100 Yr*	*48 Yr*	*100 Yr*	*48 Yr*	*100 Yr*
Wenatchee												
1960-1994	–	*5%*	–	–	–	– –	*40%*	*15%*	*9%*	--	– –	*14%* –
1970-1994	*35%*	*47%*	*5%*	*15%*	*9% --*	*20%- 6%*	*110%*	*92%*	*52%*	*48%*	*58% -39%*	*54% - 36%*
1980-1994	*75%*	*90%*	*37%*	*48%*	*43%-31%*	*54%-36%*	*170%*	*155%*	*115%*	*99%*	*124% -97%*	*107% -83%*
Entiat												
1960-1994	–	*2%*	–	–	– –	– –	*17%*	*22%*	--	–	– –	– –
1970-1994	*18%*	*23%*	–	–	– --	–	*62%*	*52%*	*16%*	*9%*	*21% -11%*	*13%-* –
1980-1994	*57%*	*67%*	*12%*	*19%*	*17%-7%*	*24%-14%*	*112%*	*100%*	*51%*	*43%*	*58% -45%*	*49% - 31%*
Methow												
1960-1994	*19%*	*10%*	–	–	–	–	*50%*	*48%*	*1%*	–	– –	– –
1970-1994	*34%*	*48%*	–	–	–	–	*100%*	*95%*	*34%*	*31%*	*40% - 28%*	*36% - 20%*
1980-1994	*32%*	*47%*	–	–	–	–	*105%*	*95%*	*38%*	*31%*	*44% - 22%*	*36% - 20%*

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6.2 Steelhead

The analyses of upper Columbia River steelhead population dynamics were limited to a single time series (brood year 1976-94) due to the lack of direct sampling of age and hatchery/wild contributions prior to the early 1980's. Extinction risk assessments are described in section 3.3.3. As was the case with spring chinook, the intent of the analysis is to evaluate whether or not the upper Columbia populations could sustain themselves in the absence of continuous hatchery supplementation consistent with the intent of ESA (e.g., Hard et al., 1992). For that reason, the projections and the survival needs were all calculated assuming that any support from hatchery production would theoretically cease immediately . The associated estimates of survival improvements needed to meet survival and recovery criteria are provided in section 4.2. For the purposes of this assessment, it was assumed that incremental improvements in survival would be realized beginning with the first simulated model year.

The results for steelhead are extremely sensitive to assumptions regarding the relative contribution or effectiveness of hatchery spawners. Returns from hatchery releases into the upper Columbia tributaries constitute a very high proportion of the adult run past fisheries. The following assessments take into account the wide range of potential contributions by hatchery spawners to natural production of steelhead in the upper Columbia.

Of the two spawning aggregates modeled, the Methow requires the largest improvements in survival to meet ESA criteria. The Wenatchee also requires substantial improvements if hatchery spawners have been contributing substantially to smolt production from natural areas. The relationship between life cycle improvements projected to meet survival and recovery criteria and assumptions about recent historical contribution rates of hatchery spawners are depicted in figures 23 and 24. Also shown are the potential contributions of HCP survival improvements and FCRPS actions (direct improvements and mitigation).

6.2.1 Effect of HCP Survival Improvement

As was with spring chinook, meeting recovery criteria (IRL level more than 50% of the time by year 48, 100) requires a greater survival improvement than meeting the simple extinction risk criteria. The model projects that improvements from current conditions are needed for both stocks. Incorporating the assumption that HCP life cycle survival goals are achieved improves the projections sufficiently to meet immediate extinction risk criteria for one scenario for both stock groups under the assumption of 25% or less relative contributions to historical natural smolt production from hatchery origin spawners Additional survival improvements would be required to meet recovery criteria under the assumption of 25% historic hatchery effectiveness.

6.2.2 Effect of HCP and FCRPS Actions

Assuming that both the survival improvements associated with the HCP goals and improvements equivalent to the direct impact of the FRCRPS system expands the set of scenarios meeting survival and recovery criteria. Under this assumption regarding the potential effectiveness of actions, short-term extinction risks would be covered if the relative contribution was as high as 50%. Longer term extinction risks, as represented by the IRL recovery criteria would be covered if the relative contribution of hatchery spawners was 25% or less. Substantial additional survival improvements would be required if relative contributions of hatchery fish exceeded 50% and hatchery augmentation were to be discontinued.

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The higher the assumed effectiveness of hatchery spawners, the greater the additional improvement in survival necessary to meet survival and recovery criteria for the upper Columbia natural steelhead runs.

hatchery fish have been as effective in contributing to wild production as wild fish, than the combined survival improvement fall considerably short. (Figure 26)

The steelhead model runs do not include continued hatchery supplementation. Life Cycle model runs incorporating continued supplemenation indicate that the combination could withstand the recent downturn in survivals. A high fraction of returning spawners would be of hatchery origin. Efforts are underway to minimize negative impacts of hatcheries in the upper Columbia through

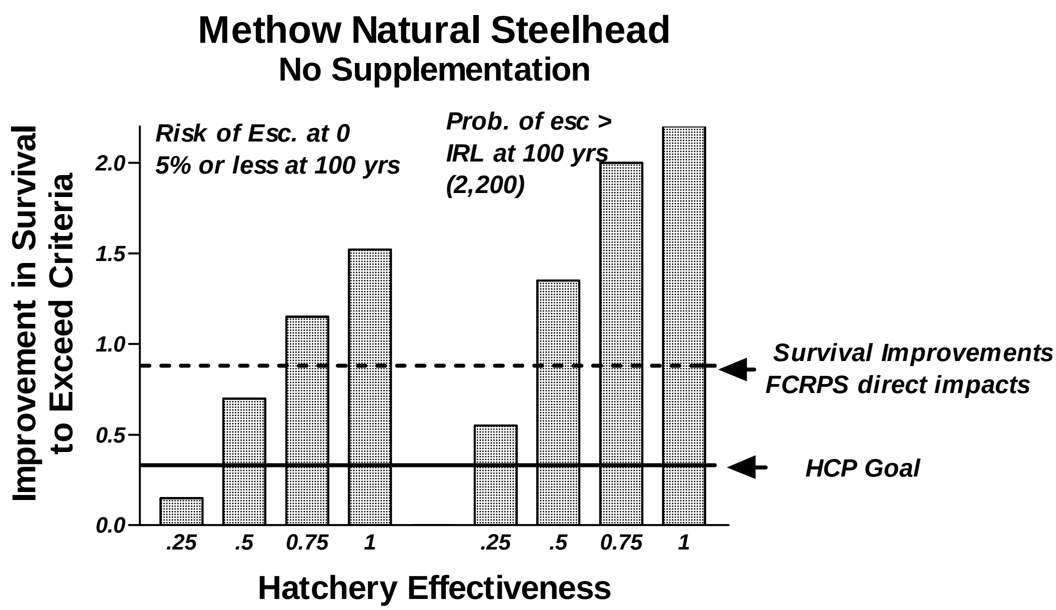

Figure 25 *Methow steelhead model results. Bars indicate needed survival improvements to meet survival and Interim Recovery Level (IRL) criteria IN THE ABSENCE OF CONTINUED HATCHERY SUPPLEMENTATION under alternative assumptions regarding the historical effectiveness of hatchery fish. Solid line = improvement resulting from meeting HCP goals. Dashed lines = cumulative improvement of HCP plus FCRPS mitigation (FCRPS draft Biological Opinion).*

improved broodstock management and fishing techniques.

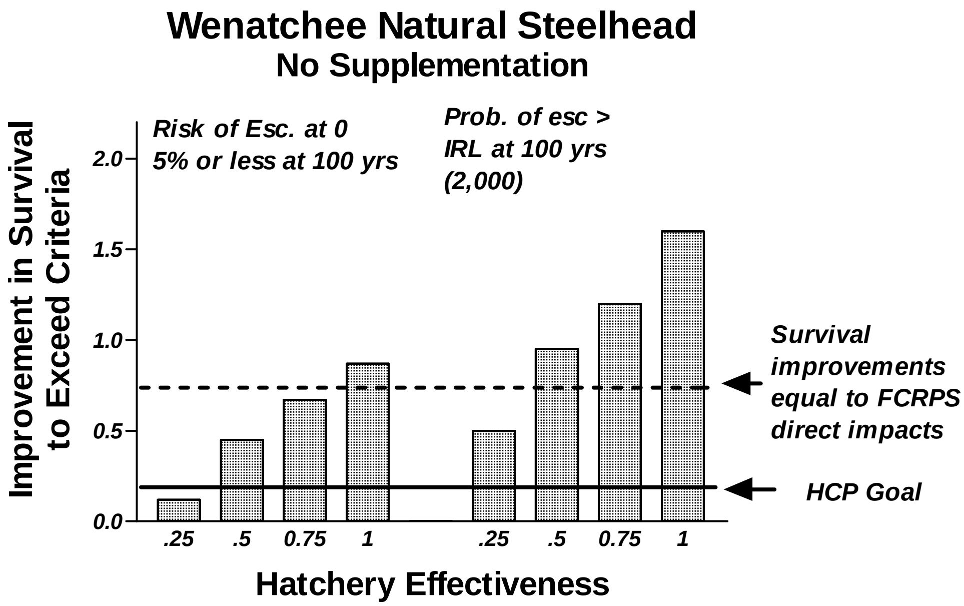

Figure 26 *Wenatchee steelhead. Bars indicate needed survival improvements to meet survival and Interim Recovery Level (IRL) criteria IN THE ABSENCE OF CONTINUED HATCHERY SUPPLEMENTATION under alternative assumptions regarding the historical effectiveness of hatchery fish. Solid line = improvement resulting from meeting HCP goals. Dashed lines = cumulative improvement of HCP plus FCRPS mitigation (FCRPS draft Biological Opinion).*

6.3 Next Steps: Monitoring and Evaluation Opportunities

The analyses described above are based on the best scientific information available. Key assumptions and uncertainties have been highlighted throughout the report. The following section summarizes opportunities to improve the knowledge base for upper Columbia listed runs.

Spring Chinook

Better estimates of survival from egg to smolt in tributary habitat is an important area for additional evaluations. A better understanding of the distribution of juveniles among rearing areas during the tributary portion of their life history phase would improve our ability to relate specific habitat improvement opportunities to population level survival benefits. Accurate estimation of the annual smolt outmigration would enable the partitioning of tributary survival from smolt to adult survival. Of particular interest, the role of downriver areas as late summer or overwintering habitat to production from specific upstream locations. What is the relative contribution of fish that migrate downstream from natal areas to use these potential refuges?

Major supplementation activities are underway for sub-populations of up river spring chinook runs. Designing those efforts to produce information on the relative success of different outplanting strategies in terms of 1) the distribution of returning spawners, and 2) the desire to avoid negative impacts on natural returns would be useful.

Steelhead

The relative effectiveness of hatchery spawners is a key uncertainty limiting understanding of the needs of wild Upper Columbia steelhead. Additional information on the relative distribution, in terms of both time and space, of returning adults of hatchery origin versus adults of natural parentage would contribute to narrowing the current range of assumptions. Recent efforts to track radio-tagged adults from mainstem dams through to the spawning grounds should be reviewed, and additional work planned as needed.

Opportunities for directed study of the relative effectiveness of hatchery and wild spawners at producing progeny when spawners are commingled should also be pursued. The 2000 FCRPS Biological Opinion calls for such studies in the basin.

Estimates of steelhead abundance are based on dam counts due to the difficulties in surveying adults during the spawning season. Studies designed to augment or confirm dam count based approaches would be beneficial to future analyses. Systematic evaluation of the use of different habitat types in the tributaries by juvenile steelhead could provide valuable insights into the potential benefits of habitat actions.

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8 Appendices

8.1 Life Stage Survival Assessment Modeling

8.1.1 Leslie Matrix Model

Leslie Matrices (Leslie, 1943, Pielou, 1969, Morris et al., 1999) are often used in the analysis of age structured populations. If a population can be expressed in the terms of a Leslie Matrix, it is possible to calculate basic population growth rate characteristics and to explore the sensitivity of population growth rates to various life history survival components represented in the matrix framework. In the analyses described below, Leslie matrices were used to estimate the combined effects of survival improvements at different life stages. Estimates of Lambda (annualized growth rates) and of the improvements in survival (expressed in terms of spawner to spawner survivals) needed to meet various survival and recovery criteria were developed using a Monte Carlo simulation model.

The adult spawner to spawner data series for each of the three upper Columbia River populations were used as the primary basis for constructing Leslie matrices. The components of each matrix were generated using a similar approach to that employed in the CRI assessments of Snake River spring/summer chinook (CRI, 1999a, b). The basic purpose of the Leslie matrix models for upper Columbia stocks was to illustrate the potential for survival change in different phases of life history with respect to annual population growth rate.

Table 8-1: *Leslie matrix format for Upper Columbia river spring chinook analyses*.

	Age 1	**Age 2**	**Age 3**	**Age 4**	**Age 5**	**Age 6**
			(1-MU)*B3* M3*F3*S1	***(1-MU)*B4* M4*F4*S1***	***(1-MU)*B5* M5*F5*S1***	***(1-MU)*B6* M6*F6*S1***
Age 2	***S2***					
Age 3		***(1-b3)*S3***				
Age 4			***(1-b4)*S4***			
Age 5				***(1-b5)*S5***		
Age 6					***(1-b6)*s6***	

The matrix (A) defined in Table 18 is a transition matrix. Multiplying this matrix times a vector representing the number of spring chinook of ages 1 - n in year t results in an estimate of the number of fish in each age class in year t + 1. The first row of the matrix represents the number of age 1+ smolts produced per spawner by age class. Each element of the first row represents the production of smolts per spawner for a particular spawner age.

Following the basic rules of matrix algebra multiplication, each element of this row is multiplied against the corresponding row element in the year t vector of numbers by age, summing the products across ages gives an estimate of the number of smolts produced by that particular brood year. The diagonal set of parameters in Matrix A are the transition coefficients, advancing each age class by adjusting for the proportion maturing to spawn and for natural mortality.

Once the matrix is filled in with parameter values, an estimate of the annual population growth rate (λ) can be obtained by transforming the matrix and solving for the resulting expanded determinant (e.g., E.C. Pielou, 1969).

The components of each element are:

(*1 - MU*): Upstream passage survival rate = 1 minus the product of passage and harvest loss rates.

B(I) I=3,4,5,6 Maturation rate by age: Proportion of adults of age I returning to spawn in year t+I. (T = brood year).

M(I) Fecundity by age

F(I) Proportion female by age

S1 Egg to smolt survival. Calculated as a product of egg-parr survival rate and parr to smolt survival rate assumption.

S2 Survival from smolt to the beginning of age 3 in the ocean. This component incorporates downstream passage, estuarine and early ocean survivals. The term can be broken down further to reflect assumptions regarding juvenile passage, transportation, early estuarine survival and estuarine/early ocean survival.

S(I) Natural survival rates from age I to age I+1.

As noted, the S2 term incorporates survival through at least three distinct time periods or phases: downstream migration, early estuarine residence/passage, and estuarine/early ocean residence. The following equation breaks down the S2 term into components that can be estimated or extrapolated from existing information.

S2 = Sp * Ser * (1-pt+D*pt)*Seo

where:

Sp = net downstream passage survival (in river and transported juveniles)

Sp = (1-pt)*Sd + pt*Sb

pt = the proportion transported at McNary
Sd = in-river survival to below Bonneville Dam
Sb = in-barge survival X in-river survival from tributary to McNary.

Ser = Survival through the transition from river to estuary. This term is difficult to directly measure. It is included to accommodate estimates of avian predation rates early in the estuarine/early ocean phase.

(1-pt+D*pt) = Adjustment to reflect differential mortality (if included) of transported fish after entry into the estuary.

Seo = Survival from post estuarine entry through early ocean residence, to the beginning of age 3

8.1.1.1 *Key Assumptions*

Applying Leslie matrix models to salmon populations requires assumptions regarding the application of information from a range of field studies. In addition, a simplifying assumptions regarding age structure, survival relationships between life history stages and the influence of natural variation are also incorporated into the assessments. The assessments described below assume that brood year age structure is fixed at historical averages for each modeled population. Annual survival between age classes or life history stages are assumed to be constants, with population specific estimates being derived from historical data series. Each component survival is assumed to be independent of all other survival rates in the model. In other words, survival through a particular life history stage does not affect the survival level at a subsequent stage. In this application, the matrix models are used for simple sensitivity analyses to illustrate the relative response of population growth rates to changes in survival at particular life history stages. No year to year variability is included in any of the model terms. Details of how the model was parameterized to represent spring chinook and steelhead populations are provided below.

8.1.1.2 *Spring Chinook*

Input parameters for the upper Columbia spring chinook Leslie matrices were derived using data from juvenile production studies, historical run reconstructions and passage survival experiments. Brood year cohort analyses were used to develop estimates from historical run reconstruction and age data.

M(I) - Fecundity by age estimates were derived by averaging across the data cited in Table 12 of Chapman (1995).

F(I) - A simple 50:50 sex ratio by age was assumed to apply to age 4+ returns. Age 3 returns were assumed to be male.

Mu - Upstream passage survival in the models is the combined survival rate taking into account all forms of adult losses. The rate is estimated as the product of the upstream dam passage survival and escapement rate (1 minus the harvest rate) of mainstem and tributary fisheries. A pre-spawning mortality rate of 10% is imposed in all runs.

S3...S6 - Ocean survival rates are fixed in the analysis. Survival at age rates used in the Pacific Salmon Commission Chinook Model were incorporated into the upper Columbia spring chinook models. Although these rates may vary from year to year, we have no way of estimating these parameters on an annual basis. Within the model, any variation in survival during this life stage would be reflected in the smolt to adult term described below.

S1: Spawner to smolt production rates were calculated by multiplying an estimate of the number of female spawners times the estimated fecundity by age and summing the results to get an estimate of egg deposition. Annual estimates of egg to smolt survival are not available for upper Columbia spring chinook salmon runs. Estimates are available for recent years for the Chiwawa basin within the Wenatchee system. The average survival from egg to smolt in the study was approximately 5%.

Smolt to ocean age 2 survivals include both downstream migration survival and estuarine/early ocean components. This aggregate survival rate was estimated through cohort run reconstructions. Under this approach, estimates of the annual ocean survival rates by age are 'backed out' of the data series through expansion factors to obtain an estimate of the number of fish alive at the beginning of age 2 for each cohort. The ratio of age 2 adults produced to smolts produced for each brood year becomes the estimated survival.

As described above, the S2 term can be 'broken down' further into a series of terms representing relatively discrete phases in the life cycle.

Sp: The weighted average smolt passage survival from the tributary to below Bonneville Dam. This term is a composite of in-river survival and transport survival. Migrants from the upper Columbia were transported from 1977 through 1995, with smolts being collected at McNary after having passed 3-5 Mid-Columbia PUD facilities, depending upon the tributary of origin. Derivation of passage survival estimates is described in Section 5.2.

Pb: The proportion of fish transported. Unlike Snake River juveniles, Upper Columbia runs were transported from only one mainstem dam, McNary. Transportation from McNary was suspended in 1995. The best index of proportion captured at McNary is believed to be the estimated detection probability of PIT tagged upper Columbia origin migrants at the project (John Williams, personal communication). Median detection rates are in the range .18 to .20 (Steve Smith, personal communication). A value of .20 was used in developing the matrix input information for upper Columbia runs.

D - Delayed mortality of transported juveniles. No direct estimates of D have been derived specifically for upper Columbia spring chinook and steelhead. For these analyses, D is set at .8 reflecting the results from recent PIT tag survival analyses for Snake River spring chinook (based on information summarized in NMFS, 2000a).

Ser - Term representing survival during the transition into the estuarine/early ocean life history phase. It is included in this analysis to allow for assessments of changes in avian or marine mammal predation rates on migrating smolts. Estimates of Ser and other estuarine survival components are difficult to obtain. Two types of estimates of lower river avian predation rates have been generated. Estimated impacts on smolt migrants have been developed by constructing quantitative feeding models of the lower river bird populations. Stomach content analyses, bird population estimates and simple models of feeding energetics have been used under this approach. Estimates of predation rates equaling 25-30% of the annual smolt migration have been generated. A second approach relies on the observation that significant numbers of PIT tags have accumulated in areas where the birds are congregated (e.g., Rice Island). Comparative analysis of detections of PIT tags at Bonneville with the results of Intensive field sampling on Rice Island indicate that predation rates on spring chinook may be lower (Byrne, et al. 1999). Ryan et al (1999) estimated terns took an estimated 2% of PIT tagged spring chinook passing Bonneville Dam, and 10% of the steelhead. The higher level of mortality (30%) was used in generating the estimated response to mortality reduction in the matrix sensitivity analysis described below.

Leslie Matrices: Results for Spring Chinook

Using the approach described above, Leslie Matrices were developed for three upper Columbia spring chinook runs (Wenatchee, Methow, and Entiat) and two upper Columbia steelhead groupings (above Wells and Wenatchee/Entiat).

The parameter values used in calculating the Wenatchee Spring Chinook matrix are listed in table 19. The basic parameters are described above. The detailed run reconstruction results provided in Attachment A were the basis for almost all of the parameter estimates. Average values across the corresponding set of brood years are used for the adult in-river survival (Bonneville to Basin term). Maturity rates (the B terms) are averages across the appropriate time frames. Fixed values were used for sex ratio and fecundity. Passage mortality rates were based on simple passage survival assumptions described in section 5.2 of this document. The egg-smolt survival term (S1, was not directly taken from the run reconstructions. These estimates were derived as described above in sections 2.1.5 and 2.2.5 for upper Columbia spring chinook and steelhead, respectively.

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Table 8-2: *Inputs for the Wenatchee spring chinook Leslie Matrix. Parameter estimates from cohort analyses are averaged over the brood years cited.*

Parameter		1970-94 Average	1980-94 Average
Harvest Rate		0.14	**0.09**
Adult Passage		0.58	**0.69**
Bonn to Basin	**MU**	0.50	**0.37**
Maturity Rate	**b4**	0.540	**0.583**
(by age)	**b5**	0.997	**0.996**
	b6	1.000	**1.000**
Fecundity	**4**	4,300	**4,300**
(by age)	**5**	5,400	**5,400**
	6	5,400	**5,400**
% Female	**4**	0.5	**0.5**
(by age)	**5**	0.5	**0.5**
	6	0.5	**0.5**
Egg-Smolt	**S1**	0.050	**0.050**
Smolt-Adult	**S2**	0.025	**0.015**
Geomean	**S2**	0.016	**0.010**
Passage Mort	**SP**	0.382	**0.371**
Bonn Smlt-Ad	**S2'**	0.069	**0.043**
Geomean	**S2'**	0.043	**0.026**
Ocean Survival	**S3**	0.7	**0.7**
(age to age)	**S4**	0.8	**0.8**
	S5	0.9	**0.9**
	S6	0.9	**0.9**

Table 8-3: *Wenatchee Spring Chinook. Parameter values derived from 1980-94 brood Wenatchee natural chinook cohort reconstructions. S1: Average/Geomean.*

	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
				39.3	84.2	84.5
Age 2	.015/*.010*					
Age 3		0.700				
Age 4			0.800			
Age 5				.375		
Age 6					.004	

Matrices were constructed for each of the three upper Columbia Spring Chinook populations. Annual average population growth rates (λ), were calculated for the 1980-94, 1970-94,and 1960-94 time periods (Table 21).

Table 8-3: *Annual population growth rate (λ) estimates for upper Columbia River spring chinook populations.*

Population	Average Generation Time	Brood Years 1980-94	Brood Years 1970-94	Brood Years 1960-94
Wenatchee	4.37	.877	.954	1.026
Entiat	4.32	.888	.999	1.030
Methow	4.40	.897	.950	1.013

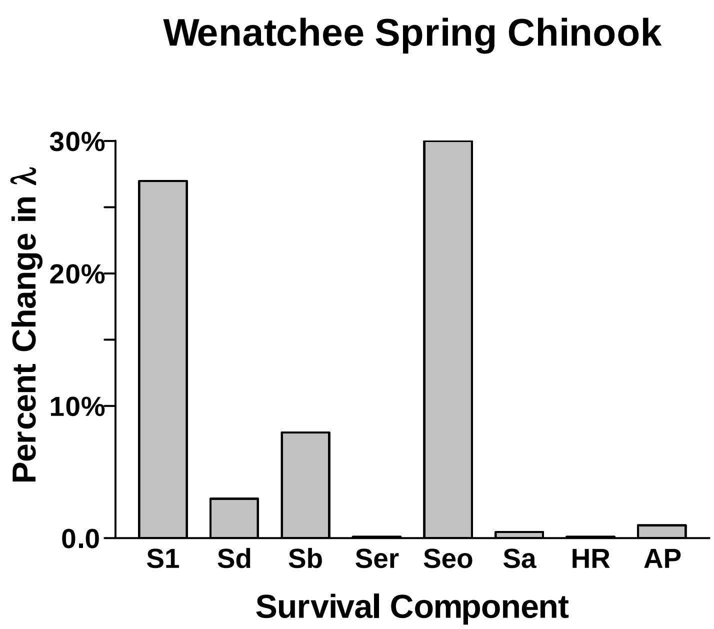

Figure 8-1: *Change in λ (annual population growth rate) resulting from a 10% reduction in mortality in different life history components. Derived from Leslie Matrix fit to 1980-94 Wenatchee data. Terms and fitting procedures as described in section (5.1.1.2).*

Leslie matrices can be used to evaluate the relative effects of an incremental reduction in mortality at different life history stages. Figure 22 summarizes the relationship between incremental changes in mortality and lambda for an example of the upper Columbia spring chinook matrices developed above . The bars in figure 19 represent the life stage components of the matrix model as described above. The height of each bar represents the percent change in average annual population growth rate resulting from a reduction in mortality of 10% at the corresponding life history stage, while holding the other life history stage survivals at the baseline levels. Reducing the mortality at a particular stage by 10% results in a corresponding increase in survival. The magnitude of the survival increase depends upon the magnitude of the baseline mortality. For example, shifting 10% of a .90 mortality rate to survival results in a proportional increase in survival of 90% (i.e., .10 + 10% *.90= .19,). In contrast, if the baseline mortality rate is .10, shifting 10% results in a proportional survival change of approximately 1% (.90 + 10% X .10 = .91). For this example, the high end of the range of estimates (30%) for lower river avian predation was used.

The resulting pattern is similar to that derived for Snake River spring chinook. S1 (egg-smolt survival) and the Seo (estuary/early ocean) survival show the highest theoretical response. Both of these phases have a high mortality rate - 90-95%. Shifting 10% of that mortality increases survival by a factor of 2 or 3. While it is mathematically possible to achieve these levels of improvement, it is not clear if it is biologically or technically feasible to accomplish such large changes. Although egg-smolt survival and its major components are each highly variable from year to year, average egg-smolt survivals for upper River spring chinook result in smolts per spawner estimates that are similar to averages for other reported examples of salmon populations exhibiting yearling migration (see Section 2.1.5 above for more detail).

There are some differences between the results reported here for upper Columbia spring chinook and the CRI analyses for Snake River spring index stocks. At least two of them are highlighted by structural differences in the way the models are set up. Recent evidence of intense predation by Caspian terns and other avian predators focus on the impacts concentrated in the lower river/estuary during the short period smolts are emigrating past nesting areas. The survival from Bonneville through early ocean residence was split into two components in the upper Columbia model to accommodate analysis of lower river predation impacts. The results reflect the high level of mortality that occurs in the estuarine/early ocean phase that follows the migration into salt water.

The annual population growth rate of upper Columbia River spring chinook is more responsive to passage survival improvements (Sd, Sb) than that reported for Snake River spring runs. The difference in response is due to the relatively high fraction of in-river migrants Harvest rate (HR) and upstream adult passage survival rate (AP) responses were similar.

8.1.1.3 *Steelhead*

Data from the cohort reconstructions and the smolt production studies described above were used to construct Leslie matrices representative of the Methow and the Wenatchee/Entiat steelhead populations. Separate matrices were developed corresponding to each of the four alternative assumptions regarding hatchery effectiveness. Age and hatchery composition analyses for upper Columbia steelhead extend back through the early 1980's. Run reconstructions were limited to the 1976 brood year and later because of the lack of data for earlier years. As a result, only a single time series was constructed for analysis - 1976 brood year to the present.

The matrices are set up to reflect the productivity of the natural component of the upper Columbia steelhead runs in the absence of continued hatchery supplementation. Variations on the matrix structure can be set up to capture continuous hatchery supplementation. Development of more detailed supplementation models is a potential objective for the next QAR Analytical Report.

Each matrix is 'populated' based on averages across brood year reconstructions of adult production as a simple function of the corresponding spawning escapements (Table 18). The cohort run reconstructions described above were used to estimate the number of adults alive at the beginning of the third year of life. The steelhead matrices incorporated an estimate of average egg to smolt survival for naturally spawning upper Columbia steelhead that was based on the adult spawner counts and estimates of the annual smolt outmigration at Rock Island Dam (see section 2.1 above). The egg deposition for each brood year was calculated using the estimated spawning escapements and assuming average fecundity. The estimated brood year egg production was adjusted using the following formula to capture the effect of the alternative assumptions regarding hatchery spawning effectiveness.

$$Eggs = \sum_{i=4}^{i=6} (Sw_{(age\ =\ i)} + Heff * Sh_{(age\ =\ i)}) * F$$

Where: Eggs = the number of eggs deposited in year(y)

Sw(age I) = the number of spawners of natural parentage in year (y) of age (I)

Heff = relative effectiveness of hatchery spawners relative to adults of natural parentage (.25, .5,.75 or 1.0)

Sh(age I) = the number of spawners of hatchery parentage) in year (y) of age (I)

F = average fecundity of upper Columbia Steelhead.

Estimates of the number of naturally produced smolts passing Rock Island Dam are available for migration years beginning with 1985. The aggregate smolt production estimates for each year are calculated as the total number of smolts leaving the tributaries to the upper Columbia. Each years outmigration includes several age components dominated by age 2 and age 3 production. Age breakdowns of each year are not available. Each outmigration was allocated to broodyears y-2 and y-3 by the average proportion by age for smolts (Peven, 1992). The age 2 and age 3 components were summed by brood year and divided by the corresponding estimated egg production to generate annual estimates of egg to smolt survival. The estimated number of smolts produced from a given brood year is a fixed number reflecting the Rock Island sampling results and the adult spawning estimates. The effective number of eggs deposited is, however, a function of the number and the proportion hatchery of brood year spawning adults. As a result, the annual estimates of aggregate egg to smolt survival are a function of the assumed effectiveness of hatchery fish spawning in the wild. This is a simple model of differential spawning success based on the parentage of returning spawners. It can reflect assumptions regarding the relative distribution of adult spawners as well as differences in parr production. More detailed models have been used that incorporate different survival rates for hatchery/hatchery, Hatchery/wild and wild/wild crosses. The simple model was used for the upper Columbia modeling for the following reasons; 1) there is support for the assumption that hatchery returns into natural spawning areas in the upper Columbia may be differentially distributed relative to natural returns and that spawning timing of hatchery returns may be earlier then for natural returns and, 2) there is no data available on the relative success of hatchery spawners in producing juveniles for the upper Columbia. The relative success of the different possible combinations of hatchery and wild parentage is likely a function of the particular differences between hatchery and wild lineages in any particular situation.

The effect of a natural carrying capacity limiting smolt production at very high spawning levels was incorporated into the smolt/production calculations by limiting the effective number of eggs to the number that would be produced if the population was at the estimated carrying capacity for the particular population.

Given the available data, the analyses described below are based on the assumption that the average egg to smolt survival is a constant function below carrying capacity for each of the major upper Columbia tributaries. Differences among the tributaries that might result from different habitat conditions (natural or the result of human actions) would obviously be averaged over given the aggregate approach.

The following tables (22 & 23) summarize the matrix parameters for upper Columbia steelhead. With the exceptions described above, the values were calculated using the same formulas as were employed for spring/summer chinook.

Table 22: *Steelhead Matrix input values corresponding to a range of possible Heff values. D is assumed to equal 1.0 in this table.*

Parameter		**1976-94 Brood Methow Steelhead**			
		Heff =.25	**Heff=.50**	**Heff=.75**	**Heff=1.0**
Harvest Rate					
Subbasin		**.05**	**.05**	**.05**	**.05**
Mainstem		**.11**	**.11**	**.11**	**.11**
Adult Passage		**.76**	**.76**	**.76**	**.76**
Bonn to Basin	**MU**	**.42**	**.42**	**.42**	**.42**
Maturity Rate	**b2**	**.009**	**.009**	**.009**	**.009**
(by age)	**b3**	**.330**	**.330**	**.330**	**.330**
	b4	**.693**	**.693**	**.693**	**.693**
	b5	**.923**	**.923**	**.923**	**.923**
	b6	**1.000**	**1.000**	**1.000**	**1.000**
Fecundity	**4**				
(by age)	**5**	**5,000**	**5,000**	**5,000**	**5,000**
	6				
% Female	**4**				
(by age)	**5**	**50%**	**50%**	**50%**	**50%**
	6				
Egg-Smolt	**S1**	**.063**	**.047**	**.038**	**.036**
Smolt-Adult	**S2**	**.036**	**.023**	**.017**	**.014**
Geomean	**S2**				
Passage Survival	**SP**	**.38**	**.38**	**.38**	**.38**
Bonn Smlt-Ad	**S2'**				
Geomean	**S2'**				
Ocean Survival	**S3**	**.8**	**.8**	**.8**	**.8**
(age to age)	**S4**	**.8**	**.8**	**.8**	**.8**
	S5	**.8**	**.8**	**.8**	**.8**
	S6	**.8**	**.8**	**.8**	**.8**

Table 23: *Example of Leslie Matrix for Methow Steelhead assuming Heff = 0.25, D=1.0.*

	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
	0	0	30.06	63.19	84.12	91.17
Age 2	0.014					
Age 3		0.793				
Age 4			0.536			
Age 5				0.246		
Age 6					0.062	

Methow Steelhead (Heff = 0.75, D=1.0)

	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
	0	0	18.20	38.25	50.92	55.19
Age 2	0.006					
Age 3		0.793				
Age 4			0.536			
Age 5				0.246		
Age 6					0.062	

Table 22 contains two examples of fitting Leslie matrices to the upper Columbia steelhead data summarized in Table 20.   The terms including egg-smolt survival (the first row of each matrix) and smolt to age 2 survival (first cell of second row) are the only terms in the matrix that are influenced by different assumptions regarding the effectiveness of hatchery spawners or differential survival of transported smolts. The terms corresponding to annual 'transfers' from one age to the next remain constant among the matrices representing different combinations of assumptions regarding the delayed effects of transportation and the effectiveness of hatchery spawners.